

SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA.
REPORT OF PROGRESS.
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REPORT
ON THE
TERMINAL MORaine
IN
PENNSYLVANIA AND WESTERN NEW YORK.

ILLUSTRATED BY
A MAP OF PENNSYLVANIA SHOWING THE GLACIATED REGION,
EIGHTEEN PHOTOGRAPHIC VIEWS OF THE MORaine, AND
THIRTY-TWO PAGE PLATE MAPS AND SECTIONS.

By H. C. LEWIS.

To which is appended
THE TERMINAL MORaine IN OHIO AND KENTUCKY, BY G. F. WRIGHT; AND
THE TERMINAL MORaine IN NEW JERSEY, BY G. H. COOK;
Reprinted from their reports.

HARRISBURG:
PUBLISHED BY THE BOARD OF COMMISSIONERS
FOR THE SECOND GEOLOGICAL SURVEY.
1884.

1883
P. 1132
p. 2

Entered, for the Commonwealth of Pennsylvania, in the year 1883, according
to acts of Congress,

By WILLIAM A. INGHAM,
Secretary of the Board of Commissioners of Geological Survey,
In the office of the Librarian of Congress, at
WASHINGTON, D. C.

Electrotyped and printed by
LANE S. HART, State Printer,
Harrisburg, Pa.

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LETTER OF TRANSMITTAL.

To his Excellency Governor ROBERT E. PATTISON, *ex-officio*
Chairman of the Board of Commissioners of the Second
Geological Survey of Pennsylvania:

SIR: It is my pleasant duty to present for your consideration a report on the geological character and geographical situation of that portion of the American glacial moraine which traverses Pennsylvania and a small district in western New York, by Professor H. C. Lewis of the Academy of Natural Sciences of Philadelphia.

If an apology for the long delay in presenting this report be considered necessary no other need be offered than a reference to the numerous pressing occupations of the Survey in the several counties of the State, sixteen of which are traversed by the moraine, and twenty-three of which are more or less covered by glacial drift, of which the moraine is merely the southernmost edge.

By foot notes to Mr. Lewis's report I have indicated in a slight but sufficient way the attention which these surface phenomena received from my colleagues during their explorations of the districts assigned to them; and the extent and value of their studies of these phenomena may be estimated by consulting their published reports, referred to in the foot notes. But, as it was impossible for any one of them to do more than collect data for a final systematic examination and description of the moraine along its whole line, Mr. Lewis volunteered to do this, and his successful performance of the task is now before you.

He has made little or no mention of the previous observations of Messrs. Carll and White in the text of his re-

port for three reasons: First, because it was desirable that the subject should be taken up afresh as the theme of an untrammelled and independent investigation; secondly, because in the already-published reports actual facts and theoretical views were commingled; and thirdly, because no one had distinctly defined the terminal moraine as a well-marked limit of the drift-deposits of northern Pennsylvania. His sole function was to take up the study of this terminal moraine at Belvidere, where it enters the State from New Jersey, and follow it closely and exclusively along its whole course to where it leaves the western border of the State and enters the State of Ohio.

This report is a plain, practical statement of what was seen along the line of the moraine itself, with numerous notes of observations covering a breadth of a few miles to the right and left of it.

Having volunteered in 1879 and 1880 an examination of the superficial deposits of south-eastern Pennsylvania for a special report on the gravels and brick-clays of the Delaware river valley, Mr. Lewis took advantage of the visit of one of our most experienced glacialists, the Rev. G. F. Wright, thoroughly acquainted with the drift, kame, and moraine deposits of New England, to study with him, from the 6th to the 13th of December, 1880, the Pennsylvania moraine in Northampton and Monroe counties.

In 1881 the Board authorized me to commission Mr. Lewis to survey and report upon the entire line of the moraine across the State. The facts of the preliminary reconnaissance in 1880 are worked into this report, it being unnecessary to give dates in such a case; but the facts then first established secured the successful prosecution of the systematic exploration of the following year.

In 1881 Mr. Lewis fixed a portion of the line between the Delaware and Susquehanna rivers. July 6th he was joined by Mr. Wright, and they explored the moraine together or separately until the 10th of August. The line between Beech Haven and Ralston was traversed by them in company between July 6th and 16th, Mr. Lewis, however, being alone between Muncy creek and Fishing creek, and Mr. Wright

alone between Muncy creek and Loyalsock. The important traverse of the Pocono plateau between Brodhead's creek and the Lehigh river was studied by them together between August 15th and 20th. Mr. Lewis afterwards revised the moraine where it crosses Huntingdon mountain. Mr. Wright then took up the survey at the Ohio State line, found the limit of the moraine at Chewtown on the Beaver river, and then Mr. Lewis and he, usually in company, but occasionally separated for a day or two, fixed the glacial limit all the way from the Ohio line northward to Salamanca in New York. The survey of the moraine between Salamanca and Lycoming creek was made by Mr. Lewis alone. In the latter part of December Mr. Wright spent a week in obtaining a more precise definition of the line near the Ohio State line, and in studying the terraces of the Beaver and Ohio rivers.

Mr. Wright's notes were intentionally written so as to be incorporated by Mr. Lewis in his report, and the two observers were continually comparing notes in the field and discussing the problems arising from the facts observed; so that the value of the report now submitted is greatly enhanced by the fact that two good observers checked and verified each others' observations at almost every point; at all events at the points of greatest interest.

Although the survey of the moraine was virtually finished in December, 1881, Professor Lewis has since then repeatedly returned to parts of the line to make fresh observations, and especially in company with Mr. E. B. Harden to obtain those photographic views of kames, erratics, scratches, &c., which have been reproduced in fac simile to illustrate the report.

It is hardly needful to remark that two trained observers could hardly carry on so extensive a line of investigation and confine themselves rigidly to a bald description of facts. Some method of accounting for observed facts is imperiously demanded and involuntarily adopted by every intelligent mind. Traces of theories—if nothing more than traces—will, of course, be found in this report, and will justly claim respectful consideration; but the sanction of the Board for

this special survey was obtained on the plea of a keenly felt necessity that the quota of facts respecting the American terminal moraine expected from the geological survey of Pennsylvania should no longer be withheld ; and in the progress of the survey the time for obtaining and publishing these facts had come. They are now presented for the use of the citizens of the State, and of American geologists. The theories of the observers are of secondary importance ; for when the text, the maps, and the illustrations of this report have been distributed, new observers will undertake to verify, correct, limit, and explain its statements for themselves. And this educational function of our reports is of the highest value.

Two series of page plate maps will be found in the body of this report.

1. A series of 12 small maps of the course of the terminal moraine carry it from county to county its entire length across the State. These maps are made to face the chapters to which they belong.

A 13th small map, on page 203, is added to show the continuation of the moraine, westward, across the State of Ohio ; its projection into Kentucky ; and its course through Indiana. This map summarizes the itinerary moraine maps with which Mr. Wright has illustrated a private report of survey of the course of the moraine through those States.

The substance of his report on the subject will be found in Chapter XVIII, commencing page 203. It is necessary for the citizens of Western Pennsylvania who desire to understand the geological origin of their river terraces, to have placed before them Mr. Wright's description of the ancient ice-dam at Cincinnati, which backed the Ohio valley waters into Pennsylvania, submerging for a time the valleys of the Monongahela and Allegheny rivers, as well as the valleys and ravines entering the Ohio river from the north and the Allegheny river from the west. In the slack water thus created the sands and clays of the moraine and of the drift-covered country behind it were deposited.

After the retreat of the ice, and the consequent destruction of the ice-dam, the slack-water pool was drained off, and the streams excavated new channels through the loose deposits, leaving fragments of them upon the hillsides. These are the terraces, gravel banks, brick-clay beds, &c., described in the early reports of the Survey, K, K², Q, Q², &c.

In my preface to Report Q on Beaver county (1878), page xxv, I summarized the facts regarding the terraces of the Monongahela, Ohio and Beaver rivers. and showed the necessity for supposing a slack-water submergence of the upper Ohio valley system; and also my ignorance of any means by which it could have been produced. Mr. Wright's ice-dam at Cincinnati furnished the means.

How high the ice-dam was cannot be known. How high a level of slack-water it maintained can only become known after a careful level-survey of the lowest divides in Kentucky by which the reservoir could deliver itself around the end of the ice. Even then we shall not know how many feet or yards higher than now these divides may have been then; nor how many feet or yards they were cut down during the many years of the existence of the ice-dam; nor whether part of the out-pour was not accomplished underneath the ice-dam; nor what was the quantity and violence of the in-pour from above; nor whether it varied much or little with the seasons; nor the length of time which the ice-dam lasted, whether years, or centuries; nor whether it was a single event, or was repeated.

All we know is that the American ice sheet at its greatest extension crossed the Ohio and stopped back the drainage of the entire water basin of East Kentucky, South-east Ohio, West Virginia, and Western Pennsylvania, up to some level, *at least 1,000 A. T.* as shown by the terminal moraine upon the hills north and south of the Ohio river, above and below Cincinnati.

Since the 1st, 2nd, and 3d drift-terraces at Beaver and New Brighton lie about 700', 750' and 800' A. T. they can now be satisfactorily accounted for.

But as the Monongahela City terraces lie at about 760',

840', 910', 1,010', 1,060', 1,120', and 1,220' A. T., (Stevenson's Report K, page 14,) and those at the Wset Virginia State line at 790', 850', 950', 980', 1,050', 1,100', 1,130', 1,195', 1,235', and 1,295' A. T., (Stevenson's Report KKK, page 252,) some additional explanation is required for the higher members of the series; which are moreover of a very different lithological composition.

If in exceptional years floods now descend the Ohio river so as to elevate the surface of its current 70 feet at Cincinnati, the imagination is lost in conjecturing the depth and velocity of glacial floods caused by exceptionally favorable melting years or seasons in the ice age.

Professor I. C. White of the West Virginia University at Morgantown on the Monongahela river just south of the Pennsylvania State line has had advantages in studying the terraces of that valley, and his remarks upon the natural consequences in Pennsylvania of an obstruction of the Ohio valley at Cincinnati—made at the meeting of the American Association for the Advancement of Science at Minneapolis in 1883—are worthy of special consideration:

"That the valley of the latter stream has been refilled with trash during some period of its history to a height of 250 or 300 feet above its present bed the evidence is most conclusive, for the remnants of this deposit still cover the surface to a great depth in long lines of terraces extending from Pittsburgh, Pa., southward along the river to Fairmount, W. Va., a distance of 180 miles, and very probably much further as I have never examined the river valley above the latter town.

"The striking peculiarity of these terrace deposits is that they suddenly disappear at an elevation of 1050 or 1075 feet above the tide, not a single rounded and transported boulder ever being found above the latter horizon, though occurring in countless numbers below this level.

"The hills along the river often rise 300 or 400 feet higher than the upper limit of the deposits, so that there can be no mistakes about the elevation at which the terrace deposits disappear. The composition of these great heaps of surface *débris* is, along the immediate valley of the river, a heterogeneous mixture of sand, clay, gravel, rounded boulders of sandstone of every size, from an inch in diameter up to four feet, pieces of coal, leaves, logs of wood, and every other species of rubbish usually transported by streams. Back from the channel of the river, however, and especially where the surface configuration would make quiet water, there occur thick deposits of very fine, bluish white clay, in which great numbers of leaves are most beautifully preserved. These clays have been extensively used for the manufacture of pottery at Geneva and Greensboro, Pa., and also to some extent at Morgantown and Fairmount, W. Va. Though the clay deposits occur at nearly every horizon, they are purest near the upper limit of the terraces, and these are consequently the only ones that have hitherto been much explored.

"In the vicinity of Morgantown, terraces of transported material occur at the following approximate (measured by barometer) elevations:

"Fifth terrace, above river, 30, above tide,	1,065
Fourth terrace, " " 200, " "	990
Third terrace, " " 175, " "	965
Second terrace, " " 75, " "	865
First terrace " " 275, " "	820

"The first terrace is the present flood-plain of the river, consisting principally of fine sand, mud and gravel. It seem to possess some respectable antiquity, however, since Mr. Walter Hough, one of my students, dug some teeth and bones from five feet below its top, which were identified by Professor O. C. Marsh as the remains of a species of peccary, an animal that has not inhabited the region in question within the American historic epoch.

"All of the other terraces have thick deposits of transported material, wherever the original contour of the surface has favored its preservation from erosion. From the top of the *fourth* terrace Mr. Keck dug a well through 70 feet of clay, gravel and boulders without finding bed rock. He also encountered logs of wood in a soft or semi-rotten condition near the bottom.

"Many other wells on the *third* terrace have been sunk to depths of 20 and 30 feet without reaching bed rock.

"The *fifth* terrace of this Morgantown series marks the height to which the pre-glacial valley of the Monongahela was silted up, partially or entirely during the existence of the glacial dam at Cincinnati, since, as already stated, no clay beds, rounded bowlders, or other transported material are ever found above its top, but instead only angular fragments of the country rock, and thin coverings of surface material which has accumulated *in situ*.

"Owing to the considerable elevation—275 feet—of the fifth terrace above the present river bed, its deposits are frequently found far inland from the Monongahela, on tributary streams. A very extensive deposit of this kind occurs on a tributary one mile and a half north-east of Morgantown, and the region, which includes three or four square miles, is significantly known as the 'flats.' The elevation of the 'flats' is 275 feet above the river, or 1065 feet above tide. The deposits on this area consist almost entirely of clays and fine sandy material, there being very few bowlders intermingled. The depth of the deposit is unknown, since a well sunk on the land of Mr. Baker passed through alternate beds of clay, fine sand, and muddy trash to a depth of 65 feet without reaching bed rock. In some portions of the clays which make up this deposit the leaves of our common forest trees are found most beautifully preserved. Whether or not they show any variations from the species growing in that region the writer has not yet had time to determine, but when a larger collection has been obtained, this subject will receive the attention that it deserves, since if the date of the glacial epoch be very remote, the species must necessarily show some divergence from the present flora.

"Of animal remains the only fragment yet discovered in this highest of the terraces is the tooth of a mastodon, dug up near Stewartstown, seven miles north-east from Morgantown." *

*I omit Mr. White's references to the valleys of West Virginia, the great Kanawha, the curious deserted Teazes valley, 15 miles below Charleston, W. V., the gravel on the summit of Sistersville Knob in Tyler county, 500'—600' above the Ohio river, &c., as unnecessary additions to the evidence found in Pennsylvania.

In chapter XIX I have appended a short description of the course of the moraine through the State of New Jersey, so carefully studied by Prof. Cook and Prof. Smock, and published with copious details in the annual report of the State Geologist for 1880. For, not only do the mountains of Pennsylvania traverse northern New Jersey, and are glaciated in New Jersey when they are not glaciated in Pennsylvania, but the New Jersey drift is swept into Pennsylvania by three considerable streams which enter the left bank of the Delaware river—the Paulin's kill at Portland, Beaver brook at Belvidere, and the Musconet-cunk river at Riegelsville. The Delaware river gravels in Pennsylvania, therefore, partly owe their origin to the moraine of New Jersey. But as no drift comes down the Schuylkill river because its water-basin is entirely south of the moraine, so no drift enters the Delaware river below Durham because the great Raritan river water-basin carries the drainage of drift into Raritan bay.

Another series of page-plate maps on a much larger scale are intercalated in the text to illustrate the more important local observations not only of the moraine itself, especially where it crosses mountain crests and river channels, or where it is notably deflected, but of kames, terraces, and erratic blocks of peculiar significance or prominence; for example, the *Jacobus creek kame* at Portland, on page-plate 8; the *Helderberg limestone boulders*, on page-plate 6; the *carboniferous boulder* containing anthracite coal and calamite impressions, on page-plate 14; *creep striæ* at the Bangor slate quarries, on page-plate 7; two boulders of gneiss from northern New York, on page-plate 10.

These maps are meant to be of use as local guides, but they lay no claim to topographical accuracy. They are, in the main, copies of parts of township maps put together as well as might be. No surveys were made to verify them or to compose their errors, and in some cases it was impossible to carry the local features from one township map into the adjoining township.

I am responsible for the portraiture of the glacial phenomena on these maps; but I was guided by the copies of the township maps used by Mr. Lewis in the field, and colored with red and blue pencil marks. In many cases (as the text of the report explains) the moraine is indistinct. It was impossible to cover all the glaciated parts of the map with markings to signify *till*, or *drift*, because in the more woody and rocky districts the exploration was necessarily confined to roads.

This report is in fact only a reconnoissance report, and neither its text nor its illustrations must be taken as in any sense a complete and finished portraiture even of the line of the Terminal Moraine, much less of the glaciated region behind it to the north, or of the unglaciated region in front of it to the south.

A sheet map of Pennsylvania will be found folded in a pocket of the volume. But, lest this should be lost, as so often happens in the course of years to the larger illustrations of reports, a small map of the State is bound into the volume at page 1, on which the line of the moraine is traced, and a tint is given to the glaciated or drift-covered region lying north of it.

On this small map the mountains of Pennsylvania are sufficiently well portrayed to show how indifferent to their existence was the sheet of ice which invaded northern Pennsylvania, and how slightly they modified the line of its frontage.

The same physical truth is exhibited in another way by page plate 1, page 12.

I am personally responsible for the representation of the ice-sheet in page plate 1, and cannot say that it satisfies me in several important particulars, such as: the regularity of its surface, the location of possible crevasses, the descent into the plain, the distribution of the bowlders, &c.; but while these are points of prime consequence in a treatise on glaciers, they are of slight importance in a report on the course of the terminal moraine in Pennsylvania.

My object in illustrating Mr. Lewis' report by this plate is twofold:—(1) to give a visible representation of the great *thickness of the ice-sheet*, by contrasting it with the section of solid rocks from the present surface down to the plane of sea-level;—(2.) to allow the reader to judge for himself how very little *eroding power* the ice-sheet had, by placing before his eye two transverse sections of the same ridges and valleys, side by side, the one operated on by the ice-sheet, the other untouched by it.

As to the first point, I have given to the surface of the ice a gentle slope southward, by making it 600' thick over the mountain, and 1800' thick over Cherry creek; which slope, if continued northward, would suffice to make the ice cover the highlands (2000' A. T.) further north, as we know that it did. Thirty years ago Agassiz gave me his law of the necessary *minimum thickness of a glacier for crossing a barrier*. It was in a conversation immediately subsequent to his study of the striae on the top of Mt. Desert, pointing from Mt. Katahdin, and descending into the sea. He said that no glacier could cross a ridge unless its thickness at the summit of the ridge was *at least one half the height of the ridge*. By this rule he judged that the ice-sheet of Maine was 1500' thick over the top of Mt. Desert; and this would account for the great distance south of Mt. Desert of the terminal moraine.

This rule was obtained by Agassiz and Desor in their long residence on the glacier of the Aar, and was based on numerous observations of local Alpine glaciers where they were crevassed in surmounting barriers of rock. Whether it is a rule to hold good under quite different circumstances, in the case of continental ice sheets, or not, we have no means of knowing. But it is the only rule at our command. I have applied it to the case of the Kittatinny mountain, and made the ice sheet 600' thick where it crossed the crest. It may have been any amount thicker for all we know.

The two sections given in this plate were constructed by H. M. Chance, some years ago, after special topographical

surveys and contour-line maps had been made by him at the Delaware, Lehigh and Schuylkill water gaps. They are published in Reports G^a and D^s, with the maps to which they belong.

I have added to the north end of the upper section one of the transverse sections of Godfrey's ridge, south of Stroudsburg, which I made in 1840,* in order to show the outcrops of Oriskany sandstone and Lower Helderberg limestone from which the bowlders were taken by the ice which now lie on the Kittatinny mountain.

Mr. Lewis remarks on page 91, that "almost every block of limestone that was taken from the Helderberg ridge in Cherry valley can be traced to its destination;" and on page 88, he directs special attention to the large numbers and great sizes of them which were carried across Cherry valley and left perched upon the top of Red ridge overlooking Wolf hollow; and to one which he found on the very summit of the Kittatinny mountain, at an elevation of 1,200 feet above the outcrop in Godfrey's ridge.

Mr. Lewis' remark may be accepted as poetically true, for there is no other source of these bowlders in all north-eastern Pennsylvania but this one line of outcrop along Godfrey's ridge, extending westward for 30 miles past the Lehigh water gap, and extending eastward for a hundred miles, up the valley of the Delaware river and across New York to the Hudson river at Rondout. Certainly every limestone bowlder in northern New Jersey, and eastern Pennsylvania has come from some point of this line; but it would baffle the sharpest observer to trace any one of them to its exact original position in the mother rock; not only because the outcrop has been so thoroughly smashed by the ice (as Mr. I. C. White has shown in his report on Pike and Monroe counties, G^a 1882, pages 227, 228 and elsewhere, respecting the massive corniferous limestone;) but chiefly because the formations are of so uniform a character all along the line. It is impossible therefore to assert that any given bowlder, or group of bowlders, has merely traveled the two or three miles of direct distance

* See Geol. of Pa., 1858, Vol. 1, page 284.

across (from the ridge to the mountain,) since it may have come across diagonally from points along the line ten, twenty or fifty miles further east.

It is true that a set of striae are shown on Godfrey's ridge, just south of Stroudsburg, in page-plate map 6, which bear S. 3° W. or nearly square across Cherry valley; but striae nearer on the mountain bear about S. 30° W.; and between Stroudsburg and lake Poconoming the recorded bearings are S. 30° , 35° , 40° , 45° , and 50° W.

Mr. White's observations of striae along the ridge east of Brodhead's creek (see Glacial map in Report G') show that the bottom of the ice moved down the Delaware river valley from Port Jarvis to the Water gap in directions varying locally between S. 30° W. and S. 50° W. Consequently, we ought to find the limestone and sandstone *débris* of the whole outcrop line for fifty miles accumulated south of Stroudsburg, and so inter-mingled, block with block, that no reference to the original place of any block can possibly be made.

The glacio-dynamic problem presented for solution by the presence of Oriskany and Helderberg erratics on the sides and crest of the Kittatinny mountain is by no means easy of solution. What kind of movement are we to ascribe to the ice-mass—or rather what various movements to its different zones—to account for blocks wrenched from the outcrops of No VI and VII being carried up a slope of 7° (average), two miles long, to a height of 1300 feet? Or (east of the gap) up a slope of 16° , one mile long, from the bed of the Delaware river to a height of 1400 feet above it?

Even if the original sites of the blocks be removed as far as possible up the river (at Bushkill, at Milford, at Port Jarvis, or at still more distant places in New York) while the upward slope of the movement is thereby lessened from 1000 feet in 3 miles to 1000 feet in 20, 40, 60, or 80 miles, it remains a fact calling for explanation that the ice has actually borne them to a higher level. That the bottom ice could not have slid bodily, like a rigid body, up

hill, is made almost certain by the fact that every Alpine glacier shows a spoon-shaped stratification of its ice. The strata represent annual snow-falls. Their spoon-shaped distortion betrays the fact that the top ice moves down the valley faster than the bottom ice, and the middle of the ice-stream faster than the sides.

That the American ice-sheet must have been stratified is evident from meteorological considerations. Every snow-storm added a new stratum to its top. Its whole thickness must have represented all the separate snow precipitations of centuries. The top strata were loose and thick; the middle strata more and more consolidated *névé*; the lower strata thin, compact, and more or less perfectly consolidated ice.

Such is the present aspect of the vertical edge of the great Antarctic glacier as pictured by South Sea exploring expeditions.

Continental snow-storms might cover the whole field with a new layer, but local or regional snow-storms would increase its thickness only where the snow-fall took place. The stratification of the whole sheet must, therefore, have been irregular, but not so irregular as in Alpine countries, where (as Viollet le Duc has specially noticed) snow-storms are excessively localized and complicated, with avalanches both of pure snow, of stratified *névé*, and of icy *seracs*. Such complications may have occurred in New Hampshire and northern New York, but hardly elsewhere.

On the other hand, the fact that we must look to the equatorial wind for the chief source of the snow-fall, and the fact that at present we see the greatest rain-fall and snow-fall take place along a geographical belt where the equatorial wind meets, rides over, is chilled by, and drops its moisture through the surface-clinging, south-setting Polar wind, teach us that the ice-sheet must have continually grown thicker along the same geographical belt, viz: that of New England, the northern States, and the lake region; in other words, along that part of the ice-sheet which lay immediately and for several hundred miles back of the terminal moraine.

The numerous annual snow-storms of the Alps do not cover up and conceal (except in winter) the lower stretches of the longer glaciers; because the snow of winter melts in summer, falls in cascades through the crevasses and issues as a river at the lower end of the ice. The same must have happened along the edge of the American ice-sheet all across the continent. This edge must have been entirely an ice-cliff, not a snow-bank.

The importance of these considerations will appear in attempting to calculate the distance to which any thread of the ice-sheet could advance southward, considering (1) its rate of motion, and (2) its rate of surface-melting. It will be seen that some method of supplementing the moving mass, some method of supplying the immense waste, some source of new supply must be devised. If the annual snow-fall be not a sufficient explanation it will be hard to imagine any other that shall meet the requirements.

The semi-fluid motions of Alpine glaciers, descending narrow valleys, by steep gradients, have been long and closely studied, and there still remains some uncertainty respecting its details. But no observer has ever had an opportunity to study, and therefore no cautious man of science will venture to assert positively anything respecting the present motion of the great Greenland glacier, or the former motion of the great American ice-sheet.

The various directions which a small fraction of its whole movement took, viz: the directions of parts of its bottom layers holding blocks of rock, are made known to us by the scratches; but of all the rest of its conduct—its internal viscosity, or rigidity—its internal warpings, twistings, shearings, descending or ascending shiftings, eschelon movements, thickening or thinning of layers, mixings of parts, transfers of *débris*, opening and shutting of crevasses against fundamental or lateral barriers, fugitive or permanent cañons—of all these things none but unexperienced physicists would pretend to know anything at all. The great book which could have informed us has been lost—burnt up like the Alexandrine library—burnt up by the sun.

That world of phenomena came and went like a vision of the night. How cautious ought we to be in every touch we give to the canvas on which we try to design some feeble picture of it, to aid our reason in explaining the traces it has left behind.

It is evident from an inspection of the course of the Terminal moraine through New Jersey and northern Pennsylvania that *the general movement* of the ice sheet crossing the State of New York was about S. 27° W. A line drawn from Amboy to Little Valley in western New York runs about N. 63° W. and the general ice flow must have been at right angles to this face line. A multitude of observed scratches in Pike, Monroe, Wayne, and Susquehanna counties confirm such a generalization. In the northern part of Pike scratches bear S. 20°, 30°, 32°, 15°, and 12° W. In middle Pike and northern Monroe scratches bear S. 25°, 30°, and 35° W. In certain localities they are observed bearing more nearly south, and in at least one place due south, even on the highest lands; and in the low lands or valley bottoms more nearly south-west; and in special localities nearly west.

There is no mistaking, however, the general aspect of the whole movement as being at right angles to the long line of terminal moraine.

It is equally evident from the remarkable bends in the line that the ice sheet as a whole was made up of *a series of ice streams*, each of great breadth and volume, like currents of water flowing side by side in a great river.

In New Jersey the terminal moraine runs from Amboy northward to Rockaway, and then westward to Belvidere. These two lines, forming a right angle at Rockaway, show that one stream of the ice sheet descended the Hudson river valley as far as New York harbor, and that another stream (north of the Highlands) flowed more south-westward from Newburgh to the Delaware at Belvidere, and projected its lobe into Northampton county.

A third stream followed the Walkill valley, between the Catskill mountains and the Kittatinny mountain, from Rondout to Stroudsburg and beyond.

A fourth stream coming from the Mohawk valley across Wayne county followed the water basin of the upper Lehigh, the Wapwallopen valley, and the Lackawanna valley as far as Berwick.

Another stream descended the water basin of the Loyalsock nearly to Williamsport.

Other streams followed the valley of Towanda creek, the valley of Wellsboro', and the valley of Crooked creek into Potter county.

In the far west the quasi-independence of the several streams in the ice-sheet, each one flowing in obedience to some belt of surface depression, river valley, lake basin, &c., is strongly marked. Three great projections of the ice sheet in the States of Ohio and Indiana are shown on Mr. Wright's map, (page 204 of this report.) The highlands of northern Pennsylvania and western New York prevented the ice from going far south. The low-lying country of the middle and lower Ohio river country permitted it to advance even into Kentucky.

Two grand divisions of the ice are plainly designated on the general map (page 1 of this report,)—one moving S. S. W. from Vermont,—the other moving S. E. up from Lake Erie into western Pennsylvania. Their two terminal moraines meet at a right angle in Cataraugus county, New York. All the striæ in northern and eastern Pennsylvania have a general S. S. W. direction. All those in north-western Pennsylvania have a general S. E. direction. In this case the convergence is against a high country.

But in other cases a mass of high land has parted two streams of ice, which, after passing the obstruction, converged on the lowlands to the south of it. This is notably the case in Nova Scotia.

At a meeting of the American Philosophical Society, May 19, 1876, Mr. Honeyman described the amygdaloid, agate, syenite, dolerite, diorite, granite, iron ore, and fossiliferous boulders, composing what he called the *Medial* and *Lateral moraine* of a glacier in Nova Scotia, descending from the Cobequid mountains to the seashore at Halifax.

The striæ on the rocks towards Halifax have an average trend of S. 5° E.

The striæ towards Windsor bear S. 20° to 30° *East*.

The striæ towards Pictou bear S. 25° *West*.

Thus the scoring of Nova Scotia has a fan-shape pattern. The scratches converge upon Halifax from the north-west, north, and north-east quarters.

This shows that two streams or belts of the great ice-sheet—one coming from New Brunswick across the Bay of Fundy,—the other coming from Prince Edward's Island across the Gulf of St. Lawrence—passed around the two ends of the Cobequid mountains, joined and flowed out together into the Atlantic at Halifax.

The massif of the Adirondack mountains in northern New York, no doubt parted two quasi-independent streams of ice,—the one following the basin of Lake Champlain and invading north-eastern Pennsylvania from the direction of Albany,—the other crossing middle New York by the way of the small lakes into Potter county, Pennsylvania. But these had flowed together long before they reached the Pennsylvania State line. A new sub-division of the combined ice sheet then took place, producing the various threads, belts, or streams of ice before alluded to, at least so far as the lower portions of the great glacier were concerned.

But it is evident that all these streams of the ice-sheet were in intimate union with each other, and that the general surface of the ice was so high above the whole topography of the country that, if a few of the very highest mountains, like the peaks of the Catskill (4000' to 4500' A. T.) were not covered, they did not disturb materially the universal movement of the upper part of the ice-sheet in its general course, say S. 27° W., as expressed by the scratches high up on the Kittatinny mountain and on the top of the Penobscot knob near Wilkes-Barre.

It is a remarkable fact that while the scratches in the bed of a valley like that of the Delaware and that of the Susquehanna, follow the course of the valley, scratches on very high land, such as the top of Penobscot knob, cross each

other at low but notable angles. This suggests variations in the direction of the movement of the upper part of the ice-sheet which I do not find explained by any facts in our possession.

Other variations from the normal direction, such as the S. and S. 5° W. scratches at 2150' A. T. in northern Monroe (I. C. White's map), may be explained by a side flow over the Pocono escarpment down into the water-basin of Broadhead's creek. To my mind this is a clear indication that the surface of the ice in Wayne county on the plateau was higher than the surface of the ice in the Delaware river lowlands of Pike county; and that this comparative lowness was due to surface waste by sunshine and south wind.

If such were the fact the descent of ice from the plateau to the lowlands must have marked the line of the submerged escarpment by a system of magnificent crevasses into which would fall to lower levels in the ice than they previously occupied a multitude of bowlders brought from the north.

In like manner the passage of the ice over the crest of the Kittatinny mountain (although the movement was very diagonal) must have developed another similar system of crevasses with like results. And it must be remembered that the more a glacier is crevassed the more rapidly it melts; especially when, as in this case, the glacier fronts the south, and the crevasses open so as to present their walls lengthwise to the heat.

An inspection of the map of New York will show that the line of the Delaware river from the Delaware water gap to Port Jarvis if projected will cut the Hudson at Catskill, its direction being N. 38° E. and wholly in the great Wal-kill-Rondout valley, south of the escarpment of the Catskill mountains. This line is so nearly the normal direction of the whole ice-flow that we can hardly suppose otherwise than that the upper and lower portions of this stream moved very nearly together; and therefore that the principal part of the moraine matter in the Delaware water gap region must be an accumulation of fragments brought steadily forward from all along the outcrops of the south face of

the Catskill and from all along the outcrop of the Helderberg-Oriskany ridge, 110 miles long.

The stream of ice, however, could not have been confined to the Walkill-Rondout valley; for, scratches S. 30° west are seen near the Wayne county line, at an elevation of 1240' A. T., crossing the valleys of the Wallenpaupack and the Delaware regardless of the local topography. The ice which made these scratches must have moved from the central plateau of the Catskill mountains, and could not have come around the north flank of the mountains from the Mohawk valley. The Catskill plateau must, therefore, have been covered with ice to a height of between 3000' and 4000' A. T., whether the bordering peaks of the plateau projected from the surface of the ice or not. If the surface of the ice in the Walkill valley lay low, there must have been a side flow on to it southward, of which the scratches give no intimation. Therefore we must believe that the ice stream in the Rondout-Walkill valley was enormously deep, its surface rising against the great south face of the Catskills nearly to their top.

We need not, therefore, look exclusively to the Pocono mountain in Pike and Monroe counties for the outcrops from which the fragments of conglomerate, &c., in Northampton county were brought. They may have come from the continuation of these outcrops along the flank of the Catskill mountains in New York.

In like manner it is impossible to believe that fragments from the Helderberg range, facing the Mohawk valley, could have been carried southward 130 miles to the Delaware Water Gap, diagonally across highlands scored everywhere with scratches bearing considerably west of south. Their origin must necessarily be sought along the outcrop of the Rondout-Walkill-Delaware river valley, which has furnished immense quantities of them, as a cursory inspection suffices to show.

The only problem of prime difficulty is how the ice managed to lift the fragments from the outcrop in the valley to the crest of the Kittatinny mountain, a problem which is

repeatedly presented for our solution at various points where the terminal moraine crosses our mountain ridges, and where blocks from a valley to the north are left perched on a mountain top to the south. And the problem is not confined to the line of the moraine, but repeats itself at points many miles back of the moraine. Twenty years ago I found Catskill red sandstone fragments which had been carried up the north flank of the Towanda mountain, in Bradford county, and been left on the edge of a swamp upon its flat summit of coal measure sandstone, and there is no Catskill country to the north of a higher elevation from which the ice could have brought them with a descending gradient.

Prof. James Hall informs me that fragments from the Mohawk valley have been carried up over the Helderberg mountain to the south of it, precisely as the Rondout-Walkill boulders have been carried over the Kittatinny mountain.

So, judging by the S. E. striae, the gneiss and granite boulders of western Pennsylvania must have been carried up from the level of Lake Erie (570 A. T.) to elevations of 1500 A. T., along the line of the terminal moraine, 1700' A. T. at Lake Chataugua, and even 2150' A. T. in Little Valley, Cattaraugus county, N. Y., (see page 156),—unless we suppose that all the Canadian boulders were borne upon the *surface* of the ice, which is clearly impossible.

Boulders of Alpine glaciers seem always to *descend* to their final resting place, but we have innumerable proofs that the American ice-sheet managed, in some way, to carry boulders from valleys up to mountain tops, although the amount of elevation in many cases, if not in all cases, may be much less than we are inclined, on a first inspection of the facts, to take for granted.

In the case of the Helderberg limestone boulders, for example, mentioned in this report, and particularly in the case of the limestone boulder found by Mr. Lewis on the crest of the Kittatinny mountain, it is not necessary to suppose that it came from Godfrey's ridge only 3 miles distant (north) in the valley below, 1000 feet beneath its

present position. Indeed, the direction of the scratches on the mountain side make such a supposition incredible. It is plain that it must have travelled down the valley of the Delaware, and may have come from the continuation of the range in the State of New York. The elevation of the surface gradually increases going east. The rise in the bed of the river for the first 35 miles, from the Delaware Water Gap to Port Jarvis, is about 200 feet. The rise from Port Jarvis to the Walkill-Rondout divide, 20 miles, is 80 feet more. There the crest of the Helderberg ridge must be nearly 1000 feet A. T. The crest of the Kittatinny mountain where the block lies is about 1500 A. T. Therefore, if the block came these 65 miles, it has been carried up only 500 feet above its original situation.

Still it remains a problem by what sort of internal movement a stone held in the ice can *ascend*, however gentle may be the gradient upwards. That internal movements take place in all glaciers is made visible to the spectator by their spoon-shaped stratification, and by the different rates at which their upper, lower, middle and lateral parts move along; as well as by the fact that they press forward over rock barriers. But so general a statement has no scientific value when evoked to explain the actual translation of a boulder up a mountain slope. In fact our knowledge of how such an operation was performed is as vague as possible, and demands the attention of hydraulic engineers.

When two equal solid bodies descending opposite slopes meet, they arrest and support each other.

Imagine myriads of cannon balls rolled from both sides to meet in the middle of a symmetrical valley. Those arriving first would remain ever afterwards the lowest stratum; those which followed would arrange themselves in higher and higher layers until the valley was full, or the supply exhausted. No shifting of places would take place, after each had found its lowest place.

But suppose opposite descending quantities of pitch, or moist clay, through which cannon balls were scattered, to meet along the middle line of a valley; the two advancing

fronts would mash against each other, and thicken, upwards; the included cannon balls rising vertically in the thickening mass; the thickening being in proportion to the height and weight and rigidity of the masses of clay pressing from the side slopes upon the middle line which had come to rest.*

By substituting plastic ice for moist clay, and rock bowlders for cannon balls, we get an idea of how the American ice-sheet may have carried up (diagonally) the masses which it tore from low-lying outcrops to higher levels, and even over mountain crests.

In England evidence of a tolerably satisfactory character has been obtained, that a more powerful Scotch glacier has met square in the face, has arrested, and has turned up and pressed back the front of a weaker English glacier, mingling with it; so that English blocks traveling northward were first elevated vertically and then borne backwards miles *in the rear of the places from which they started*. It would require a more exact knowledge of the facts to make all the circumstances of this case credible; but, even if not true to the extent alleged, or at all, the statement may still serve as an illustration of operations which no doubt took place at numerous points and in various stages of the growth of the American ice-sheet.

When an Alpine glacier which has been retreating for some years or centuries re-advances, it pushes before it all the terminal moraine matter which it had left behind it in its retreat. But it effects this because its advancing front end is covered with immense masses of rock blocks. These serve it as an iron shoe serves a wooden plow; or a tempered edge serves a soft steel chisel. Without its armament of rock the ice alone could effect little and would ride or flow over its old moraines.

A terminal moraine is often described as if it were merely the tumbled off accumulation of the medial and lateral moraines which cover the surface and sides of a glacier. But the fact is that a glacier is like a plum pudding, full of scattered sand and stones from top to bottom and from

*The principle is illustrated by "creeps" in the underclay of coal mines.

side to side, all of which are delivered at its front end down the valley. The surface exhibition is made much stronger than it would otherwise be by the perpetual melting of the upper surface and sides of the glacier. This brings the plums in the pudding to the surface and mixes them with the medial moraine blocks which have ridden down from the forks of the valley. A constant concentration of the *débris* of the whole glacier thus goes on at its surface, in spite of the occasional loss of some of the stuff by dropping into crevasses; the blocks thus temporarily lost rejoining their fellows at the surface, if the glacier be long enough, lower down the valley; or issuing midway of its front end in the mass of the terminal moraine.

The main point to observe is that a glacier is not a stream of pure ice with trash on its surface and at its edges, but a stream of ice more or less charged throughout with trash; and the charging of the whole mass is a process which is mainly accomplished in the upper valleys where avalanches of snow and rock stuff are continually combining their heterogeneous contributions.

Whether such was the constitution of the great American glacier cannot be known so far as I can see; but I can conceive of no other theory adequate to account for the remarkable distribution of its boulders; and I have portrayed it on page plate 1, with no intention of defending even the possible truthfulness of the representation, but as a sort of protest against a very common practice of writing about pure top ice, ground moraine, &c., in a vague pseudo-scientific style, as if all had been made quite comprehensible, which in fact is not distinctly comprehended by anybody, and perhaps never will be.

For example, how can any one know the condition of the bottom ice of a glacier 3,000 or 5,000 feet thick? Col. Ludlow's recent tests of knickerbocker ice show that cubes of it 6 and 12 inches square crush under varying pressures of from 325 lbs. (in a warm room) to 1,000 lbs. (in a cold room) to the square inch. Does it not follow that no glacier more than 2,300 feet thick can have solid ice in its lowest layer.*

* Distilled water weighs 0.0361 lb. per cubic inch.

The crushing of ice is a demoralization of its crystalline structure—a reduction of the mass to an amorphous, plastic, viscous and partly liquified condition—consequently, a minimizing of its ability to grasp, break off and carry forward blocks of rock. On a smooth down-slope a perfect fluid may transport a solid body; but on a rough up-slope transportation can only be accomplished either at high velocities, or by a rigid or quasi-rigid matrix, with a *vis a tergo* superior to the frictional resistance. By actual observation under the overhanging edges of Alpine glaciers it is known that where a block is caught and held by a slight inequality in the rock-floor, the apparently solid ice moves over the block in a helpless way without budging it from its position.*

Could we apply the rates of advance and of surface-meeting of Alpine glaciers to our former American ice-sheet, we should arrive at strange conclusions. Hugi's hut on the Aar glacier, built in 1827, was found by Agassiz, in 1840, 1561 yards lower down the valley. It had moved 109 yards per annum.

In 1841 Agassiz planted poles in the ice 5 yards deep. In September they stood 3 yards above the ice. The rate of melting was, therefore, 3 yards per hot season.

In 1864 Tyndall planted three poles in the ice of the Glacier du Géant, 595 and 533 yards apart. The daily speed of these poles was $20\frac{1}{4}$ inches for the upper pole, 16 inches for the middle, and $12\frac{3}{8}$ inches for the lower pole per day.

* In building the great dam at Furens in France 92.5 pounds per square inch was taken as a safe limit of calculation in providing against the crushing weight of masonry. The Ban dam was built on a safe limit of 114 pounds per square inch, or 16,416 pounds per square foot. But in some instances the lower courses of high buildings have suffered from the weight of the material. I have heard 900 feet given as the greatest possible height of a Philadelphia brick wall before crushing at the bottom. The weight of masonry may be assumed at 144 pounds per cubic foot; that of water at 62.5 pounds. Therefore 3000 feet of ice weighs as much as 1300 feet of masonry. But as mountains still stand firm which are 25000 feet high, there seems to be no reason for suspecting the soundness of the bottom ice of a glacier only 3000 feet thick. Whatever tendency to crush there may be is withstood on all sides. (See E. S. Gould, in Van Nostrand's Eng. Mag., April, 1884.)

The ice *gathered on itself* therefore, in descending the valley, at the rate of 8 inches per day in a space of 1100 yards. Of course there must have been a notable shifting of the ice-zones in the body of the glacier, and consequently a shifting of the levels of its inherent bowlders.

If the Rondout-Walkill stream of our ice-sheet moved only 100 yards per annum (like the glacier of the Aar), a section of its ice starting at the Hudson would require $\frac{228800}{100} = 2288$ years to reach the Delaware Water Gap. This is of itself sufficiently startling.

But supposing the original section of the ice at the Hudson to be 3000 feet thick,* and that its surface melted 10 feet per year, (like the Glacier du Géant), it would have melted entirely away in 300 years, *i. e.* before it had made more than one seventh of the journey to the Delaware Water Gap.

Shall we increase the rate of motion sevenfold? or diminish the rate of melting to one seventh? Even then the last trace of ice would be at water level at the Water Gap instead of riding over the mountain top.

Or shall we supply the annual waste by an incredibly great annual snow-fall?

Or shall we accept Dufour and Forel's conclusion "that glaciers absorb a great portion of the water contained in the atmosphere, appropriate it, and convert it into ice."

Or shall we supplement the volume of the valley stream by perpetual side-flows of upper ice from the Catskill-Pocono plateau on the north?

Or shall we confess that we know absolutely nothing at all about it?

The thickness of the American ice field *as a whole* cannot be measurable, since not a fragment remains of it except in Greenland. All we can do at this late day is to note the height of the mountains which it once covered, and the highest limit of the scratches which it left on the rock surfaces of those which it did not cover.

* The valley of the Hudson was filled with ice above the level of the Mountain House, near which Ramsay described his horizontal scratches many years ago.

This last-mentioned kind of evidence, being negative, may deceive us.

The snow surface of a freshly covered plowed field is as irregular as the surface of the plowed ground; but successive deep snow storms will ultimately fill up the furrows and produce an even level surface. No ordinary amount of snow-fall however will bring the snowy slopes on two sides of a vale upon one and the same level. But many centuries of snow-fall in excess of snow-melt would level up an entire region, so that hills and vales would vanish and nothing remain but one universal gently sloping plain from the interior to the seaboard.

Such an operation has been imagined as occurring on a still larger scale in the ice age, during which snow is supposed to have covered a fourth of the Continent to the tops of the highest mountains, that is, not only the mountain tops of Canada 3,000 feet above tide, but the mountain tops of New Hampshire and New York 6,000 feet above tide.

But why should this snow field be supposed to have had a level upper surface? Why should it not have merely masked the greater inequalities of the Continent, while it obliterated the smaller? Why should such a snow field be 6,000 feet deep over the plain of Montreal because it covered Mt. Marcy to the south and Mt. Washington to the east?

The usual answer to these questions has been: Because the snow field, as a whole, had become an ice field as a whole, and moved southward everywhere as a whole, and, therefore, must have had all the characteristics of a glacier, one of which is to move with a regularly sloping surface downwards. It is quite unimaginable that ice should carry the rocks of Mt. Marcy and land them on the highlands of Potter county or Warren county in Pennsylvania, unless the whole intervening low lying region of New York were filled with ice to a slope commencing with an altitude of 6,000' and ending with one of 2,500' above tide. In like manner the New England section of the ice sheet would have a surface sloping from 6,000' in New Hampshire to sea

level at Nantucket and Long Island. If all the Canadian boulders in western Pennsylvania and Middle Ohio came (as the scratches show) from the basin of Lake Erie, that basin must have been filled with ice to a height of at least 3,000' above tide.

The Greenland glacier is the only extant sample of the ancient American ice-sheet. As viewed by Edward Whymper from various mountain tops along Davis strait from lat. $68^{\circ} 30'$ to $71^{\circ} 15'$ a distance of 200 miles, it was seen to be quite continuous, without break or depression of any sort, snow and ice covering up the country so absolutely that not a single rock or crag could be detected in any direction.*

Baron Nordenskiöld in his now celebrated journey from Disco bay eastward over the ice-sheet of Greenland, in July of 1883, began by ascending shore slopes of gneiss rock, from 600 to 1000 feet high, back of which lay the "ragged and impassable edge of the ice-sheet." After getting on to a smoother surface (from which projected a rocky ridge 680' A. T.) the party advanced, as fast as numerous crevasses and other obstacles allowed, by successive camping places always ascending. At the third camp the ice surface was 1000' A. T.; at the 4th, 1080'; at the 5th, 1250'; at the 6th, 1270'; at the 7th, 1500'; at the 8th, 1820'; at the 9th, 2500'; the interval distances being about 7 miles; total distance, say 42 miles; total height gained from 3d to 9th camp, say 1500 feet; upward slope per mile $36'$.

"The 9th camp lay on the west side of an ice-ridge, close by a small shallow lake, the water from which gathered as usual into a big river, which disappeared in an abyss with azure-colored [ice] sides."

"From this point we had a fine view of the country to the west, and even saw the sea shining forth between the lofty peaks on the coast. But when we reached east of this ice-ridge the country was seen no more, and the horizon was formed of ice alone."

*Whymper found "the height of the interior" of Greenland in the latitude of Umenak (about $70^{\circ} 30'$) "considerably exceeded 10,000 feet."—*London Nature*, February 28, 1884, p. 417.

"I had particularly requested each man to be on the lookout for stones on the ice; but, after a journey of about one third of a mile from the ice-border, no stone was found on the surface, not even one as large as a pin's point. But the quantity of clay-dust (*Kryokonite*) deposited on the ice was very great, I believe, several hundred tons per square kilometer."*

The slope up eastward continued from the 9th camp for a while, and then the journey seemed to be across a dead-level plain. But this was an illusion. The barometers testified to the continuance of the upward (eastward) slope of the ice-plain;—ten miles to camp 10, 2920';—7½ miles to camp 11, 2945';—10½ miles to camp 12, 3220', A. T.; total distance, 28 miles; height gained, 720'; upward slope per mile 26'.

"Our road was still crossed by swift and strong rivers, but the ice became more smooth, while the *kryokonite* cavities† became more and more troublesome" When the rain stopped "we strained our eyes to trace the mountains which would break the ice horizon around us, but it was everywhere as level as that of the sea" "We came to the conclusion that they were unfortunately no mountains, but merely the dark reflexion of some lakes further to the east in the ice-desert."

The next three days showed the slope thus: 8½ miles to camp 13; 14 miles to camp 14; 13 miles to camp 15 (4,035' A. T.); distance 37½ miles; height gained 815'; upward slope per mile 22'.

Then 12 miles to camp 16; 11 miles to camp 17; 5 miles to camp 18; 5 miles to camp 19 (4,975' A. T.); distance 50 miles; height gained 940'; upward slope per mile 19'.

The short distances of the last two days were caused by a sleety south-east snow storm, which turned the whole surface of the ice-plain into a snow-bog.

The party had traveled over the ice-plain in a straight

* Two thirds of a mile.

† This curious dust, supposed by some to be meteoric, Baron Nordenskiöld connects with a minute vegetation. It plays a most important rôle in facilitating the melting action on the surface of the glacier.

line about 160 miles, ascending about 4,000 feet, to an altitude of about 5,000' A. T.

Before returning the Lapps were sent forward on snow skates, and returned in 57 hours, reporting that they had traversed an additional 75 miles eastward on an ice surface excellent for "skidoring over," to a point (by their barometer readings) 6,660' A. T. beyond which the snow plain still continued on with no trace of any land beyond. This last upward slope was per mile $22\frac{1}{2}'$.

After the first 30 miles the Lapps could no longer find water. Further on the ice became perfectly smooth; thermometer about 29° F. At the point of return the snow was level and packed by the wind. *All was smooth ice, covered by 4 feet of fine and hard snow.*

"The inland ice was formed in terraces, thus: first a hill, then a level, again another hill, and so on."

From this remarkable exploration of the Greenland continental glacier we learn for the first time the only facts which are applicable to the explanation of some of the main features of the great extinct American ice sheet.

At all events we have portrayed a bed of solid ice, with merely a thin top dressing of snow; its front edge about 1000' A. T.; its surface sloping back for at least 215 miles to a height of about 6,660' A. T.

This gives an average gradient of only about 26' per mile, or a little more than a quarter of one degree. But it is of considerable importance to notice that the *slope per mile* was at first 36', then 26', then 19', and then $22'$.

Baron Nordenskiöld observes in conclusion that Greenland between lat. 68° and 69° "has the form of a round loaf of bread, with sides which gradually and symmetrically slope down to the sea, *i. e.*, exactly the shape which I pointed out as a necessary condition if the entire country should be covered with a continuous sheet of ice."

But how can this concealed form be known, seeing that all possible existing inequalities are covered by the ice-sheet? And how is such a form of the interior to be harmonized with the form of the east and west coasts, along which Alpine ranges of uncovered rock run? It seems to

me more reasonable to suppose the heart of Greenland a plain;* and to account for the great height of the ice in the center (with sloping surfaces towards the coast mountains) by the cold of the center, and the vast meltings which he describes as going on at lower elevations down the slopes, the surface of the ice-sheet being wasted away with great rapidity during summer, "large and swift rivers" plunging from the surface into profound crevasses. If the ice-sheet moves at all it must fill up valleys; and these valleys may be bounded by mountains higher than our Catskill mountains, of the existence of which the level surface of the ice at 5000' to 7000' above the sea will of course give no hint.

In the case of Greenland we see the ice-sheet, but know absolutely nothing about the concealed land.

In the case of our glaciated area we see the once concealed land, but know absolutely nothing about the surface of the ice-sheet which covered it in a forgone age.

The Greenland glacier therefore gives us very little aid in reconstructing the departed state of things resulting in the production of our drift and terminal moraine.

But if we have a right to argue from the approximate level surface of the ice-sheet over Greenland that a similarly gently upward sloping ice-plain extended from the terminal moraine in Pennsylvania and New Jersey northward towards Canada in spite of the intervening mountains and valleys, we have the same right to argue back from these topographical features in Pennsylvania, New Jersey, New York, &c., that the solid land under the Greenland glacier is similarly accidented, and is not, as Baron Nordenskiöld imagines, like the top of a flat loaf of bread.

. A gradient of 25 feet to the mile, starting from the terminal moraine on top of the Huntingdon mountain in Columbia county (1500' A. T.), and proceeding N. 31° E. (at right angles to the whole line of the moraine from Salamanca to Amboy) by Great Bend and Little Falls to White Face mountain (in the heart of the Adirondacks west of Lake

* By plain, I mean an ordinarily accidented surface, traversed by ridges and valleys, like most lands.

Champlain) would make the height of the ice-surface at Great Bend (on the State line) $70 \times 25' + 1500' = 3050'$ A. T., at Little Falls (in the Mohawk valley), $80 \times 25' + 3050' = 6050'$ A. T., and at White Face, $100 \times 25' + 6050' = 8550'$ A. T.

More than 2000 feet of ice would then cover Mt. Marcy and Mt. Washington.

Such is a fair example of the theoretical consequences of depending on the present Greenland glacier for restoring to us the lost form of the ancient American ice-sheet.

But we can trust it to inform us of certain main facts: (1.) That the surface sloped south-westward. (2.) That this slope was increased by the abundant meltings of the lower parts of the slope, while the higher parts escaped the influence of sunshine and equatorial air to some extent by reason of a perpetual temperature below 32° F. (3.) That numerous large rivers traversed the slopes and plunged through crevasses to the rock-bottom, producing the usual phenomena of cascades and torrents. (4.) That the ice was solid and pure from top to bottom, with merely a coating of fresh-fallen snow. (5.) That not a stone of any kind lay upon the surface except just back of its edge where it was making the terminal moraine

As to the rate of waste of the surface, and as to the rate of the forward movement of the ice, the Greenland glacier has as yet taught nothing.

But from Alpine glaciers both the rate of surface-waste and the rate of forward motion, in feet, per day and per year, have been obtained; but these rates are so variable, so local, and so complicated in their causes as to be of little or no assistance to us in our efforts to imagine a rate of surface-waste and a rate of southward movement for the extinct American glacier.

The melting energy of direct sunshine upon a continental plane surface has been calculated and is well known; but the Alpine glaciers flow far down into midsummer regions of temperature between high reflecting walls of rock, so

that the middle line of the stream is, in some cases, 150 feet higher than the edge of the ice flowing along the hotrock wall. One year the ice will be subject to intense reflection; another year avalanches of snow and séracs (half-melted pinnacle ice) cover the reflecting walls and arrest the ice-waste. A branch glacier when disjoined from a main glacier merely sends a river of water to flow underneath it down the valley; but, when favorable years have reunited it to the main stream, it takes its place beside the main glacier, elevates the common ice-surface by side-pressure, and accelerates the ice-flow down the main valley.*

Sometimes the Alpine glaciers push their ends rapidly down the valleys.

After the rainy summer of 1815, the Distel glacier pushed forward, until 1817, at the rate of 50 feet a year: and the Lys glacier at the rate of near 160 feet a year.

In 1853 the Zermatt glacier advanced 75 feet.

In 1842 a Tyrolean glacier at the head of the Oetz valley advanced 656 feet in 67 days, nearly 10 feet per day!—In 1843, 1844 it advanced more slowly;—but in the summer of 1845 its rate of advance was *32½ feet per day!* In fact the whole mass was slipping bodily forward. In 1854 it began to draw back its end, but it took 34 years to retire to its original limits.†

All Alpine glaciers are subject to these oscillations. The ice ever flows forward, down the valley, but its rate of motion being variable and the rate of melting being variable, the front end of the glacier sometimes advances, sometimes retreats. Sunshine, warm winds, and rains unite to fluctuate them all. Long severe winters, and rainy summers between 1812 and 1817 caused all the glaciers of Mount Blanc to descend to a very low level. In 1820 some of them were still advancing, while others stopped, or sensibly retreated until 1826. Then they resumed their advance until 1837. Retreating for a while they again hesitatingly ad-

*All this is admirably told with illustrations by that master of the subject, Viollet le Duc, in his "Mont Blanc." London, 1877.

†Prof. Charles Martins of Montpellier.

vanced until 1854; when a general retreat commenced which lasted to 1877.*

A continuous succession of 774 such years as 1812 to 1819, during which the front of the Rhone glacier rapidly advanced, would cause it to fill the great valley and extend to Soleure.†

A fall of the mean annual temperature of Geneva from $48^{\circ} 5'$ to 41° F. (the summers being colder, the winters remaining what they are) would lower the perpetual snow line to 6,400' A. T. and the terminus of the Mount Blanc glaciers from 3,770' to 1,312' A. T. which is the level of the plain of Switzerland.‡

We can understand, then, how the low lands of Switzerland became covered with a sheet of ice several thousand feet thick, during the ice age; hills, vales and lakes all disappearing from view; to re-appear in a later age coated with drift-stuff and sown with Alpine boulders of all sorts, as it is in our day.

The upper limit line of ice-abrasion in the great valleys of the Alps is 4,000 feet above the present streams; and the highest boulders on the side of the distant Jura lie 2,000 feet above the plain. Consequently one unbroken sheet of ice must have covered the country, having a surface sloping northward 2,000 feet in 50 miles, *i. e.* on a gradient 40 feet to the mile.§ Had there been no side outlets into France, and northward into Germany, no doubt the gradient would have become diminished to that of the Greenland glacier, and the ice would have overflowed the Jura mountains, landing the Alpine blocks in Burgundy; as Laurentian and Adirondack blocks were landed in Pennsylvania.

The analogy would be perfect if Canada were a strictly Alpine country; if instead of a smoothed off highland only 2,000' or 3,000' A. T., it exhibited ranges of peaks rising

* When Viollet le Duc wrote.

† Calculation by Pichard and Secretan.

‡ C. Martins, *Revue des deux Mondes*, 1867.

§ I give these figures roughly to impress the main fact. The exact figures can be found in numerous publications. I have repeatedly seen the boulders on the slopes of the Jura. One of the highest lies by the side of the old Roman road from Bienne to Basel on the south slope of the Weissenberg.

to heights of 10,000' and 15,000' A. T. As it is we must be satisfied with the very limited massifs in New York and New Hampshire, with peaks of only 5,000' and 6,000' A. T., and no *cirques* in which to convert snow to névé and névé to ice.

But Greenland is evidently one single *cirque*, sufficient unto itself. We may conclude, then, that a larger lower area of extra snow is in certain circumstances equivalent to a smaller but higher area, for generating an ice-sheet,—and so leave the question of the origin of the American ice-sheet unanswered.

The general direction of the ice-flow in *northern* Pennsylvania is parallel to the general direction taken by the main body of the ice from the Montreal plain, by way of Lakes Ontario and Erie, across northern Ohio and Indiana, down the water-basin of the Wabash river to southern Illinois. Consequently the ice-flow in *western* Pennsylvania, which was at right angles to the general direction, must have been a side-movement towards the edge of the sheet west of the Allegheny river, to supply the waste caused by an excess of melting on the line of the terminal moraine.

In 1875 Mr. Charles E. Hall studied the Lehigh river drift gravels south of the Lehigh water gap, and the drift dam across the mouth of the Aquanichicola creek behind the gap, previously observed by Mr. H. M. Chance in connection with the crushed slate outcrops both north and south of the gap, which he considered evidences of the passage of a glacier down the valley of the Lehigh through the gap.

In a short communication to the American Philosophical Society, September 17, 1875, he said:

“South of the Lehigh gap, about one mile below the chain-bridge, on the east side of the river, is a railroad cut through the slates of the Hudson river group, overlaid by a large bed of sand, gravel, and boulders, having all the characteristics of a glacial deposit. The slate has a dip to

the S. E. The upper edges of it are broken and crushed over to the S., showing a force and weight moving in a southerly direction and obliging the slates to conform to it.

"A similar exposure was observed three fourths of a mile below Bowman's, second station above Lehigh gap. Here, in a railroad cut through the shales of VI (Lower Helderberg), on the east side of the river, the rock is exposed for more than a hundred feet, dipping S. 20° E., the line of exposure being S. 40° E. Parallel to the exposure, or diagonally across the strike, are the edges of the shale overturned and broken, in some places to the depth of five or six feet. Here, too, the broken edges all incline to the S. E., indicating the direction of the moving mass to be towards the gap. The shale is very much crushed near the surface. Above it is a heavy bed of fine sand, *angular* fragments of rock, and large boulders, most of them from the Oriskany, some from the Chemung, but none from the Medina of the Blue (Kittatinny) mountain.

"Two hundred yards back of the hotel at Bowman's, on the road to Fireline, the slates of the Hamilton present a similar appearance, the upper edges overturned and broken, showing a movement to the south-eastward.

"We may conclude from these facts that the bed of the present Lehigh river marks, to a great extent, the course of the glaciers."

At the Delaware Water Gap, Mr. Hall observed "decided glacial action" about 4 miles from the mouth of Marshall's creek, on the road to Craig's Meadows, in scratches on the level Oriskany sandstone beds, often covering several hundred feet of the rock laid bare by the road, and pointing S. 28° W. towards the gap. "The northern side is more deeply grooved and more polished than immediately south of it."

He noticed also "evidences of a moraine" about one mile north of the mouth of Marshall's creek, near the mill dam; large deposits of drift, "probably glacial," near Craig's Meadows; large deposits of gravel and boulders, "evidently glacial débris," south of the gap, (in Northampton county;) polished and grooved Medina sandstone surfaces,

about 2 miles west and south-west of the gap, (on the mountains;) and beautifully defined terraces between the gap and Broadhead's creek.

"These facts tend to prove that the gaps existed before the glacial epoch, and that the present rivers mark, to some extent, the courses of the ice, at any rate, towards the close of that period."

Mr. Hall, however, saw no *scratches* either north or south of the Lehigh gap; and this fact draws a critical distinction between it and the Delaware gap, and makes it probable that the outcrops of slate have not been bent over and crushed by ice, but by the downward creep of all inclined land surfaces.

The angular *débris* overlying these crushed outcrops is, however, more difficult to explain, and is a testimony to the presence of ice, although it cannot be positively denied that angular as well as subangular and rounded boulders, may not have been brought down the Lehigh Valley by great floods, with floating or winter ice, from the now ruined moraine above Mauch Chunk. On the other hand, the fact that most of these angular boulders are of *Oriskany sandstone*, the only outcrop of which crosses the Lehigh Valley just at Bowman's, is decidedly against the notion that they form part of a moraine. If a glacier descending the valley had deposited them, they would be mixed with great quantities of Catskill rocks. This fact and the absence of scratches taken together seem to settle the question of a Lehigh Valley local glacial in the negative.

The same line of argument may be pursued respecting the lateral valleys of the Delaware and Lehigh river system in the South mountain and Durham hills region, where the absence of any boulders not at home in the region itself is satisfactory evidence that the great ice-sheet which crossed these mountains farther east in New Jersey did not reach to them in Pennsylvania, and that the boulder deposits of the Durham creek valley must be otherwise explained, as well as such deposits of sand, gravel, and boulders as the one in West Philadelphia mapped by Messrs. J. H. and E. B. Harden, and described by Mr. Hall in the Proc. A. P.

S., November 7, 1875, page 633, which can hardly be a moraine, although lying on smooth (unscratched) rock, since no glacial scratches nor moraine ridges have ever been remarked in the Schuylkill river water-basin above Philadelphia.

Two remarkable phenomena, however, stand in the way of a positive and final assertion respecting the limit of the southward extension of the northern ice in spite of the well marked line of its terminal moraine, viz: (1.) scratches observed on the mountains of Schuylkill and Dauphin county; and (2.) vast grooves or notches in the crest of the Kittatinny mountain, for which no explanation is suggested by the drainage system of the country.

(1.) Respecting the first very little can be said, but that little is important.

In 1850-51, Prof. Edward Desor of Switzerland and myself observed glacial scratches pointing southward upon the bare outcrop of Conglomerate which makes the crest of Locust mountain west of Ashland. The testimony of the distinguished glacialist to their genuineness is sufficient. We were both of us perfectly well acquainted with the nature and aspect of "slickensides," and felt sure that these polished surfaces, grooves, &c., were not of that kind, nor could they have been produced in that way; for they crossed the eroded edges of the beds.

Some years afterwards I observed horizontal grooves traversing the natural vertical east wall of the small and unique notch in the crest of the Fourth mountain where it is crossed by the turnpike from Harrisburg to Halifax. The opposite west wall had been cut to the vertical by the engineers, and was covered with sections of blast-holes; but the east wall had not been touched, and was covered with *horizontal* glacial grooves and scratches crossing the steeply south-dipping bed-planes. In this case I had no one with me to verify the observation, but I feel as sure of the nature of the exhibition as in the former case.

The little turnpike notch is quite unique, and its origin must therefore be extraordinary. It presents the appear-

ance of a hack with a tool, as if the crest of the mountain had been violently struck and a small piece chipped out. In fact I can conceive of no other explanation. The top of the mountain is say 1,200 (?) feet above present tide level. Its long, sharp, horizontal crest has never been scrutinized I believe by any one for traces of glacial action, and it is quite possible that it may exhibit such traces. But if the turnpike notch with its horizontal scratches was produced by ice, it must have been by an iceberg, floating over the region of eastern Pennsylvania when that region was submerged by a rise of the sea level amounting to at least 1,200 feet above the present datum. If such a suggestion be accepted, then the scratches on the Locust mountain crest west of Ashland would share in the proposed explanation.

(2.) The *Wind Gap* is one of the strangest and most inexplicable features of the earth's surface. I know of nothing exactly like it anywhere else; and although I directed attention to its remarkable character and to the important bearing it must have on the theoretical physics of geology many years ago, I am not aware that any serious attempt has been made to construct a satisfactory hypothesis of its origin.

It is unique in its shape and in its situation. It does not fall under the head of mountain notches, nor under the head of mountain ravines, any more than under the head of water gaps.

A long, straight, sharp-crested ridge, 1000' feet high on a base two miles wide, is here—not split by a fault, nor gapped by a stream, but—*worn smoothly through* down to half its altitude. The raggedness of the mountain crest ceases and smoothly-rounded slopes descend to the smoothly-rounded bottom of the gap, which is lined with sand and gravel. The contours above it (east and west) and below it (north and south) are equally regular and symmetrical. If the whole thing had been carefully sand-papered it could not have been made to differ more strikingly from all the other gaps in Pennsylvania. Its great

width and depth set it apart from all the *notches* and *road-gaps* of the State; not to speak of the fact that these are connected with cross-faults, side throws of the strata, or variations of thickness or hardness in the crest-rib-rocks; whereas here there is no break in the axial line of the mountain, nor any change of stratification. It is evidently a deep cross-groove smoothly made and finished by some agent of erosion acting slowly and continuously—but an agent quite different from a river.

Indeed, river agency is out of the question. The Wind Gap, instead of being at the outlet of a water-basin, is above the level of the divide between two water-basins. In the valley beneath it (on the north) Aquanichicola and Cherry creeks have their head springs, and flow away from it, the one west to the Lehigh Water Gap, the other east to the Delaware Water Gap. Below it (on the south) are the springs of the Bushkill descending to the Delaware at Easton.

Were this Wind Gap situated in Southern Pennsylvania or Virginia it seems to me that no explanation for it could be suggested. But it is situated, very suggestively, just in front of the Terminal moraine; *i. e.* not more than 2 miles south of Lake Poponoming (one of the kettle-holes of the moraine), and not more than 7 miles west of where the moraine passes over the crest of the mountain.

Considering then what has been said above of the repeated sudden and considerable oscillations of the termini of the Alpine glaciers, I can see no serious objection to the supposition that the front of the ice sheet may at one time have advanced the necessary two miles and banked itself against the mountain at the Wind Gap. How it could produce the Wind Gap under such circumstances without leaving a moraine to tell the tale may perhaps be explained by supposing the advance to have been made by the upper ice only, and towards the close of the ice period, long after the moraine had been accomplished. But there arise such questions as:—Was the Wind Gap cut by a large river flowing over the surface of the ice?—Was the cutting begun and finished on this occasion?—Does its depth measure the length of time during which the ice remained

thus in advance of the moraine?—How far down the valley of the Aquanahicola did the ice advance go? &c.

In any future investigation of the origin of the Wind Gap the fact that there extends *southward* from the level of the bottom of the gap a fan-shape sloping plain of *rounded boulder drift*, which has evidently all come through the Wind Gap, and has probably been brought through it by the agent which made the gap (although that cannot be taken for granted) must be taken into consideration. This drift talus is an item of the utmost importance; since it connects the primary phenomena of glacial erosion with the secondary phenomena of our glacial and post-glacial terrace and river bed deposits; and since it may have a vital influence on any theory of general submergence.

In a foot-note to Report G^a, page 63, 1882, I have suggested a method by which the Wind Gap could have been made, which I may here repeat. Supposing the ice-sheet in Monroe county to have remained limited by the line of the moraine at *Lake Popponoming* (610' A. T.), an ice dam at the *Lehigh Water Gap* (370' A. T.) only 600 feet high would produce a lake over a large part of Monroe and Carbon counties, the surface of which would stand at the level of the bottom of the *Wind Gap*, (978' A. T.) But nothing less than 1100' of ice on the Lehigh would suffice to deliver this lake over the crest of the mountain in order to *commence* the Water Gap; and it is hard to see why that point should have been selected for the operation. The unglaciated condition of Carbon county quite precludes the possibility of a Lehigh ice dam 1100' feet high, or anything approaching in character such a phenomenon.

The bowl under *Bake-oven Knob* six miles west of the Lehigh Water Gap is as mysterious as the Wind Gap. Here the mountain has not been gapped, only slightly notched at its crest; but a huge half bowl has been scooped out of its southern slope. Cliffs of rock a hundred feet high at the crest overhang the west side of the bowl; and at the top of the cliff the crest is almost 100 feet higher than anywhere

else along the line of the mountain for fifty miles, so that the *Bake-oven* is a land-mark for four counties.

It looks as if the bowl had been made by some kind of water-fall; but if so the mass of water must have been extraordinarily great, and must have shot clear of the top of the mountain—an arrangement only possible in case the back valley were filled with ice to a height exceeding that of the mountain.

All the difficulties encountered at the Wind Gap meet us here in an exaggerated form; and therefore a discussion of them is, for the present, useless. All the more, seeing that the geological survey has not yet been able to make contoured maps of the neighborhood.

The whole subject of terrene elevations and subsidences is shrouded in mystery. Whether we discuss the great deposits of the Devonian system; or the successive sea levels apparently indicated by the coal measures; or the undoubted height of the Triassic sea level above the present 1,000' A. T. contour line; or the laying bare of the Cretaceous and Tertiary deposits of the Atlantic and Gulf coast region; or the great height of the Champlain (or Albany) clay especially in Canada;—we are everywhere met and confused by a multitude of half verified, half concealed, and more than half incomprehensible details, which sometimes suggest vertical movements of the land, and sometimes variations in the general sea level of the globe; while it is certainly true that every movement of the earth crust, however local and in whatever direction, must necessarily imply some cotemporary change of absolute ocean level all over the globe.

In the case of the coal measures, if they were deposited in a closed basin, the rise of water level can be readily explained by the income of sands and clays, and by the known ability of bog vegetation to grow on slopes. In the case of the glacial phenomena, we have the abstraction of sea-water to form ice on the land, and its restoration to elevate the surface of the sea. But in all cases the volcanic and plutonic movements which have been perpetually taking

place all over the world come in as factors of unknown and unknowable value to complicate the investigation. One thing only is certain, that there are terrace deposits at an elevation of 800' and 900' A. T. in front of the terminal moraine which can hardly be explained on any hypothesis but that of an overflow of the sea to at least that height above its present coast line.

Whether this submergence took place while the ice still covered the highland, or took place after its disappearance, is as yet a very difficult question to answer. But the answer is hardly made more easy by a recent suggestion based on the weight of the ice-sheet.

That the weight of the ice-sheet had no effect in the way of depressing the continental land area which it covered, seems to me as certain a truth as any truth within the limited range of our knowledge of the physics of the globe, and I base my conviction

(1.) on the observed stability of mountain masses of rock weighing foot for foot two or three times as much as ice. To say nothing of Alps, Andes, the plateau of Central Asia, &c., it is only requisite to observe the Catskill tableland, with its average elevation of 3,000 feet, equal in weight to a bed of ice 7,500 feet thick, and to ask for evidence of any change of sea level due to its pressure—for any proof that it is maintained in its position by such a balance of gravity between it and neighboring regions as could be disturbed if an additional thousand feet of rock (or 2,500 feet of ice) were superimposed upon it.

We have good reason for believing that the Catskill plateau has lost by erosion the greater part of its top hamper of Pocono, Mauch Chunk, Pottsville and Carboniferous strata, and was therefore originally at least 10,000 feet higher than it is at present; in other words, has lost in weight an equivalent of say 25,000 feet of ice. Yet the coast survey soundings show that during at least one period—and the latest period—of this erosion, the continental area of which it forms a part, instead of *rising* by a relief

of pressure, has *sunk* at least 100 fathoms in relation to sea level; that is, if the movement has been one of the land, and not, as I prefer to consider it, one of the sea. For the general sea level is never stable, but is always changing from year to year, as well as from age to age.

(2.) on the absence of consistent testimony to such supposed depression of the land deducible from the dips of any part of the glaciated region. The gentle general southward slope of the Palæozoic measures from Canada into Pennsylvania is not only directly assignable to the system of Appalachian flexures, but is various in its geographical sub-divisions (which it would not be if effected by the removal of a regular overlay of ice). It, moreover, represents at its northern limit a total thickness of now eroded formations, which (however reduced by theoretical considerations regarding the thinning of the formations northward) greatly exceeded in weight-value that of the utmost theoretical thickness of the ice-sheet; to say nothing of the fact that if the melting of the ice could have elevated the area, the erosion of the rocks would have produced the same effect in a much greater degree.

(3.) In well-studied sea-girt glacial regions like the British isles no coincidence between the maxima and minima of ice and the maxima and minima of subsidence has been proved. On the contrary, the latest word on the subject (not necessarily the truest because the latest) affirms precisely the contrary. Mr. Jas. Durham in the Geol. Mag. of December, 1883, page 546, sums up the interpretation of the facts thus:

“From the foregoing it seems evident (1) that throughout the first maximum extension of the ice-sheet the land was at least as high as at present; (2), after the ice had disappeared, or at least withdrawn from the sea-shore, the great submergence of 500 feet took place; (3), that during the last maximum extension of the ice-sheet the land stood higher than at present; (4), that when the great load of ice was *removed* from the land, the submergence of upwards of 100 feet took place; (5), that after a vast mass of morainic *débris* had been laid down on the sea bottom, it

rose up higher than at present, so that a forest flourished upon what is again the bed of the ocean; and (6) when all abnormal conditions had disappeared the land was again depressed and reelevated to its present level. A series of geological phenomena more inconsistent with the new theory it is impossible to conceive."

If instead of using the theoretical terms *elevation* and *subsidence of the land*, the terms *subsidence* and *elevation of the sea level* be substituted, then the whole aspect of the case changes, and there comes into view another possible explanation of part of the phenomenon; for no one will deny that the restoration of the melted ice-water to the ocean must have elevated the sea level over the whole globe, to an appreciable degree, whether sufficiently for explaining observed facts or not.

Mr. Lewis, during his exploration of the terminal moraine, collected characteristic specimens of boulders of all kinds to the number of 2,000. These are permanently labeled, and a list of them will be found in the next volume of the Catalogue of the Museum of the Survey. Many of them are mentioned in the text of this report, but without the attached numbers in the Catalogue; those of them so mentioned will be indicated in the Catalogue by references to the pages of the report.

The future study of this collection ought to advance our knowledge of the various movements of the ice; as the study of the boulders distributed over the plains of Switzerland enabled Prof. Guyot to trace the ancient glacial streams back to their respective sources in the Alps; and as the boulders recently detected in Holland and Belgium prove to the satisfaction of European geologists the former extension of the ancient Scandinavian ice-sheet across and beyond the North Sea to the borders of France.

Mr. Lewis' survey of the gravel and clay beds of the Delaware river valley is reserved for another report. The subject has been studied by him with close attention for

several years, not only for its own proper geological and economical importance within the limits of the State, but in its very extensive geological and archæological bearings upon the Cretaceous, Tertiary, Glacial, and Post-glacial formations of the Atlantic sea-board.

J. P. LESLEY.

1008 Clinton street, Philadelphia.

April 21, 1884.



LETTER OF TRANSMITTAL.

Prof. J. P. LESLEY, *State Geologist*:

DEAR SIR: In transmitting to you the following notes on the terminal moraine, I desire to express my obligations to the Second Geological Survey, which has afforded me the opportunity to undertake an exploration which to me has been of the greatest interest.

I desire also to express my thanks to those citizens and railroad companies which have rendered assistance in the prosecution of my field work. Especially, however, am I indebted to my friend, Prof. George Frederick Wright, of Oberlin, Ohio, who for six weeks, about one third of the time employed in field work during 1881, gave me valuable assistance. While we have been together over a great part of the field, portions of the moraine in central Lycoming and southern Venango counties were traced by him alone, and his experience in the glacial phenomena of New England has been of great value in correlating similar deposits in Pennsylvania.

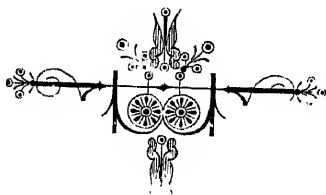
Hoping that the enclosed report will meet with your approval,

I remain,

Very respectfully yours,

H. CARVILL LEWIS.

GERMANTOWN, *October 15, 1882.*



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CHAPTER I.

The Glacial Epoch.

When Agassiz, some forty years ago, after a prolonged study of the Swiss glaciers, announced the conclusion that large portions of the continents of North America, as well as of Europe, were covered in recent geological times by an immense glacier hundreds of thousands of square miles in extent and several thousand feet in thickness, geologists the world over were startled at what then seemed a most improbable hypothesis. To-day there is hardly a truth in geology more widely accepted or capable of more conclusive proof.

Yet even now the history of the "great ice age," so lately come to an end, is so surprising that the mind requires the strongest proof of its existence before accepting as probable the remarkable events of that period.

That in an age immediately preceding the time of man's appearance a continuous ice-sheet advanced from the north across the Laurentians, the Adirondacks, the Catskills, and the successive mountain ranges of Eastern Pennsylvania, finally to stop within sixty miles of Philadelphia; that another lobe of the same ice-sheet crossed Lake Erie, advancing into Western Pennsylvania to within thirty-five miles of Pittsburgh, and that this continental glacier probably covered the entire north-eastern part of the continent as a mass of ice so deep at one time as to not only fill the valleys, but to flow over the mountain summits, often moving up-hill regardless of topography, is a conclusion so astonishing that it would not be strange were it at first

received with incredulity. It is here proposed to inquire briefly into the nature of the facts which have led to such a conclusion.

A study of the glaciers of the Alps has shown that a glacier in its motion produces several characteristic phenomena, which, remaining long after the glacier has retreated or disappeared, are sure indications of its former presence.

1. Of these one of the most important is the planing, scratching and polishing of the rock surfaces over which a glacier has flowed. This phenomenon, which may be seen at the foot of many of the Swiss glaciers, is due to the grinding of the sand and fragments of rock either imbedded in the ice or pushed along by it under the glacier. By this means all the soft or decomposed portions of the rock floor are scraped off, and even the hardest rock is ground down and polished. The smoothly rounded surfaces of rock often thus produced, have been called by De Saussure "*roches montannees*," from their fanciful resemblance to the backs of sheep. On such rounded surfaces the side from whence the glacier came (the *stoss side*) is the most worn, while the opposite side (the *lee side*)* is often more rough and uneven. The direction of the glacial flow can thus, on close scrutiny, often be determined.

Most of these polished domes of rock, as well as surfaces which have been ground flat, are marked by grooves or scratches made by hard fragments of rock frozen into the bottom of the ice, and acting like a graver's tool as the glacier moves onward. These markings, or *glacial striæ*, which vary from the finest lines perceived with difficulty to deep furrows many yards in length, are indubitable evidence of glaciation, and their direction corresponds with that of the movement of the glacier.

2. The stones which act as tools to produce these striæ, as also those fragments which are ground over one another either in the crevasses of the glacier or at its contact with rock, are themselves striated or scratched. These scratches

*Also called "shock and lee sides," or "crag and tail," the latter when associated with debris.

may cross each other in several directions, as the stone turns over in its motion; but on the larger pebbles the lines are approximately parallel to their larger axes. Not only are stones carried along the base of a glacier often thus marked, but they also acquire a characteristic shape, being rounded or smoothed at the sides and rough or jagged at the ends. The shaping and striation of the stones are characteristic glacial phenomena, and since running water almost immediately obliterates the scratches and rounds the stones into smooth pebbles, one thus clearly distinguishes them from any aqueous deposits.

3. A third feature of glacial action is the transportation of boulders and rock fragments. Noticed long ago in Switzerland by De Saussure, it was not until 1840 that the studies begun by such local observers as Venetz and Charpentier, and immediately afterward enlarged and systematized by Agassiz, Desor and Guyot, followed by Forbes, Rendu, and others, proved that glaciers flowed with a motion resembling that of a viscous body, the central portion flowing more rapidly than the sides, and the upper layers faster than the lower. The laws of this motion, as discovered by Agassiz and his companions, and the theories of its cause, as variously enunciated by Forbes, Tyndall, Moseby, Croll, Thompson, and others are of great importance in attempting to understand the movements of the far greater glacier whose traces in Pennsylvania we are about to examine. By reason of this onward and downward flow of a Swiss glacier, any rock fragments which fall on its surface or, which are broken off by being frozen into the ice, are transported to the point in the valley where the glacier comes to an end. In this way a heap of detritus is gradually dumped down at the terminus of the glacier, forming a ridge of unstratified glaciated material at right angles to the motion of the glacier. This ridge of debris has been called a *terminal moraine*. The mass of debris accumulated under the glacier is the *ground moraine*, while the lines of waste at the side of the ice stream are its *lateral moraines*. When two glacial streams, each having lateral moraines, meet, as is often the case in Switzerland, a *medial moraine* is produced

and extends from the junction of the two lateral moraines along the middle of the glacier in a line parallel to its motion. When a glacier retreats, these moraines, more especially the terminal moraine, in which huge boulders are often imbedded, may be left to mark its former extension.

These three phenomena, then—(1) the scratching and polishing of the rock surface, (2) the shaping and scratching of the moved fragments, and (3) the transportation of boulders and consequent formation of moraines—are the most prominent records left by a glacier, and are not known to be produced by any other agency.

By far the most important fact brought out by the study of the glacial phenomena of Switzerland—a fact first noted by Charpentier, but first given the prominence it deserves by Agassiz—was that the glaciers of that country once had an enormously greater extension than at present. That the glaciers are now rapidly retreating may be readily seen by any one examining the region immediately in front of the foot of the Rhone glacier. This glacier, after a course of nearly 15 miles, descends steeply into the valley of the Rhone, and there spreads out into a flat semicircular foot, which, year by year, retreats farther back at a rate of some fifty paces annually. The sides of the valley below the glacier up to a certain height are bare of vegetation, and with their freshly smoothed rock surfaces contrast strikingly with the slopes above which they have not been so recently glaciated. The height of this surface above the valley descends by a curving line away from the glacier until it reaches the plain farther down the valley, at which point a low irregular ridge of sand, gravel, and boulders, some of which are scratched, stretches across the valley as a terminal moraine. A plain covered by similar *débris* reaches from here to the foot of the glacier and under it, forming the ground moraine, and the evidence is complete that the glacier recently extended down to this terminal moraine. But farther examination shows that at one time the glacier extended still farther. Other moraines may be seen farther down the valley, each marking halting places, or perhaps oscillations, in the retreat of the glacier; and the most com-

plete evidence has been collected, in the form of striated surfaces, transported boulders, and moraines, to show that the Rhone glacier once formed a mighty *mer de glace*, 270 miles long, 3000 feet deep, and in some portions 50 miles broad, which, joined by the gigantic glaciers from Mt. Blanc and other Alpine regions, flowed across Lake Geneva onward to the Jura mountains. Immense boulders, sometimes containing thousands of cubic feet,* and great masses of angular débris carried from the Alps, form a remarkable terminal moraine high up on that side of the Juras which faces the Swiss plain, and prove that the ancient glacial stream, at the time of its greatest extension, stretched continuously outwards from the Rhone valley, abutting upon the Juras with a thickness there of over 2000 feet.

All of these boulders may be traced by their lithological characters back to their source, high up in the Alpine valleys. (as was first done by Dr. Guyot and others,) and the testimony is conclusive that glacier ice was the only possible method of their transportation. It has been shown that equally enormous streams of ice flowed from the Alps southward toward the valley of the Po, far into Italy; and subsequent investigations showed that the Pyrénées, the Apennines, the mountains of Scotland, Scandinavia, Siberia, India and New Zealand once radiated glaciers of large size.

In America, the great ice sheet, about to be described, over-spread its north-eastern portion, and large glaciers descended from the Sierra Nevada and Rocky mountain ranges; but the few glaciers at the present time existing within the United States are insignificant in size and confined to high elevations.

Having thus briefly reviewed the evidences of a former more extended glaciation in different mountain regions throughout the globe, we may enter upon the consideration of those two great regions of the world where the glacial phenomena are on so grand a scale, and where the conditions of glaciation are so different from those of regions

* One of these, the famous "*Pierre à bot*," at Neuchâtel, a mass of granite containing 40,000 cubic feet or 3000 tons in weight, was brought from Mont Blanc.

where there is a definite centre of radiating glaciers that the greatest difficulties have arisen in attempting an explanation of all the facts, opinions differing even now as regards some of the most fundamental propositions.

These two regions are north-western Europe and north-eastern America. Of the two, the glaciation of the latter is the most difficult to comprehend, since no center from which glaciers could radiate has yet been discovered.

The great "Northern Drift," as it has long been called by geologists, is a scattered deposit of stones and clay, which, unlike the stratified gravels and clays of our river valleys, is a confused mixture irregularly dumped over the ground, thick in some places and thin in others, and often unstratified and unsorted by water. It is an impure clay, filled with stones of all sizes and shapes, generally rounded more or less, yet often sharp. They lie at all angles, confusedly mixed together, and upon close examination many of them show fine striations, the majority of which are longitudinal. Large boulders are scattered through and upon this deposit, and are often many feet in diameter. Stratified gravelly deposits are also present in large quantity.

This unstratified deposit has been called by the Swiss geologists *till*, a term which will be used in this report to distinguish this unstratified stony clay from various other diluvial and drift deposits which occur in the region covered by the Northern Drift, and which all of them *overlie the till*. The term *drift* will be used to designate all detrital deposits which have been moved, by whatever agent, from their original place of occurrence, including, among other kinds, *glacial drift*, *river drift*, and *frost drift*, the latter term here designating such angular drift as creeps down any declivity through the successive freezing and thawing of the loose mass, aided by gravity. The "Northern Drift" designates those detrital deposits which in North-eastern America and North-western Europe have generally been drifted in a southerly direction. The *modified drift* of some geologists is a general term, including all such portions of the Northern drift as have been assorted by water action.

A peculiarity of the Northern Drift is that it is not con-

fined to the valleys and lowlands, but may be found covering the whole northern region, mountains as well as valleys, without reference to any lines of drainage, as an almost continuous mantle. Upon sharp mountain summits, and upon steep slopes, it may be represented by transported boulders and striated stones alone; but, again, it may be as finely developed upon a high mountain plateau as at the level of the sea. The till has as much depth and has just as characteristic features on the Allegheny plateau in Potter county, Pennsylvania, for example, at an elevation of 2500 feet, as it has on Staten Island almost at the level of the sea. While the components of the *till* vary with the strata from whence they were derived (in great part the underlying strata) the general features of the deposit are remarkably uniform throughout the drift-covered region of the two continents.

The transported boulders, or "erratics," which are scattered in great numbers throughout this region, can be shown to have been derived from a more northern source, sometimes hundreds of miles distant from their present position. Often perched upon mountain summits, they can frequently be shown to have journeyed in a southerly direction across successive mountain ranges, finally to be left at a point which may be more elevated than their source. These boulders, as well as the smaller stones imbedded in the till, are frequently smoothed off and covered with striæ and scratches, especially if the rock is hard and fine-grained. Nowhere outside of the region of the Northern Drift, *except in the vicinity of glaciers*, ancient or modern, do similar striated stones occur. No other features of the till are more striking or more clearly explain its origin.

Those parts of Europe and America covered by the Northern Drift, are also characterized by rounded and smoothed ledges, and striated rock surfaces. Exposed surfaces of rock at places where the till has been removed by any means, are ground down, and if the rock is sufficiently durable, show scratches and grooves as though made by the movement across it of some solid heavy mass. These grooves or striations are almost always in a southerly di-

rection and correspond with the direction in which the accompanying boulders have been transported.

These features, together with certain stratified deposits and some high level gravel banks and other phenomena, more particularly to be described hereafter, characterize the so-called Northern Drift, which, covering all North-western Europe and North-eastern America, has been the cause of so much discussion among geologists, and is, even yet, of such great interest.

The earlier geologists supposed that the Northern Drift was caused by a polar deluge sweeping furiously toward the equator, engulfing mountains and valleys alike, and carrying with it great masses of stones and rubbish, which, after the subsidence of the flood, remained as the deposits just described. It is agreed, however, that no satisfactory cause for such a flood or for such waves of translation exists; nor can it be shown that water, however heavily laden with detritus, can either scratch the stones it bears, striate and groove rock surfaces, or form unstratified *till*. Nor can any flood transport great boulders across successive mountain ranges to positions often higher than the parent rock.

Another theory was therefore proposed. Great icebergs were supposed to have floated upon an inland sea, and to have both carried the boulders, and to have striated any rocks on which they might have grounded. Against such a theory the absence of any evidences of water action throughout large regions covered by the till, the absence of any proof that icebergs can produce striæ, the difficulty of explaining the transportation of boulders from valleys to mountain tops, and especially the entire uncertainty of any shore line for such an inland sea, militate strongly. This Iceberg Theory is still supported by a few geologists, and will, therefore, be again referred to in our description of the glacial phenomena of Pennsylvania.

The glacial theory of Agassiz, on the other hand, somewhat modified by more recent discoveries, while it explains the observed facts, is based upon observations of phenomena produced at the present time. For, the mantle of till, the polished and striated rock surfaces, the transported and

glaciated boulders, are phenomena now produced by a glacier. So well does every detail of the Northern Drift correspond with those described as found at the base of the Swiss glaciers, that, as Professor Whitney remarks,* when describing the ancient glaciation of the Sierra Nevada: "There is nothing doubtful about the matter. Once one enters upon a formerly glaciated region there is no possibility of mistaking the origin of the phenomena presented to view. Polished and scratched surfaces, smooth and rounded ledges, transported boulders, and, above all, moraines of various kinds, are all recognized with the greatest ease by the observer, making a combination of circumstances which no one familiar with glacier regions could for a moment hesitate to refer to the true cause."

In Europe the phenomena of glaciation extend southward to a line which has been ascertained to run approximately, as follows: Crossing England, from its south-west corner in an easterly direction, so as to pass not far from London, it crosses the North Sea and enters southern Holland between Antwerp and Amsterdam, whence it traverses Prussia, Saxony, Silesia, and Poland, until, entering Russia, it curves north-east, passing east of Moscow, and finally reaches the Arctic Ocean just west of the Ural Mountains.

The great ice-sheet which, at the time of its greatest extension, covered all the region lying to the north of that line, surrounded and covered the mountains of Great Britain and Scandinavia, where local glaciers remained, producing their characteristic markings, long after the continuous ice-sheet had departed.

There are many evidences in Europe of a second glaciation of more limited size and of local origin.

The direction of striæ and the transport of boulders indicate that the mountains of Scandinavia were the principal radiating point from whence the ice-sheet spread out so as to cover such a large part of Europe. At the same time the Swiss Alps supported an immense *mer de glace*, which radiated huge glaciers in every direction.

*Memoirs Mus. Comp. Zool., Cambridge, vol. vii, No. 2, p. 23.

In America we have proof of an even more extended glaciation, with the remarkable difference that whereas in Europe there is an elevated centre of dispersion in the Scandinavian mountains, in America the apparent center of the glaciated region, so far as is now known, is occupied by the depression of Hudson's Bay and the surrounding lowlands. The centres of dispersion in America appear to have been the ring of mountains which surrounds this depression. The mountains of Greenland, Labrador, northern Canada, and perhaps also of New Hampshire and northern New York probably contributed great glaciers which, at the period of maximum glaciation, joined with the polar ice cap to form an immense ice-sheet so thick as to completely cover over the whole region, and to flow southward over a great portion of the continent, even Mt. Washington being buried under it.

The limits of the northern drift deposits of North America have not yet been exactly defined. Very little is known respecting it west of Manitoba. The line of its southern edge however has been studied from the north-west corner of Dakota, whence it passes through the center of Nebraska and the north-eastern corner of Kansas, continuing eastward through the middle of Missouri to the Mississippi river near St. Louis, across Illinois and Indiana into Kentucky; recrossing the Ohio river above Cincinnati; then trending north-east to the Pennsylvania line a few miles north of Beaver. In Pennsylvania, as will presently be stated more in detail, it passes north-west from Beaver county to Warren county, where it enters New York. Making a sharp curve in Cattaraugus county, New York, it again enters Pennsylvania in Potter county, and passes south-east to Belvidere in Northampton county; whence it crosses New Jersey to Staten Island, and traversing the whole length of Long Island, appears on Block Island, Naushon and Cape Cod, and is probably continued by St. George's bank and Sable Island shoal outside of Nova Scotia; whence passing on south-east of Newfoundland and south of Greenland, it may possibly have joined the ice-sheet which covered north-western Europe.

This American ice sheet, extending over an area of five

million square miles, flowed outwardly towards its edge, even although, as in eastern Pennsylvania, the bottom strata of the ice sometimes *flowed up hill*. Throughout the greater part of the United States and Canada the direction of flow, as shown both by glacial striæ and transported boulders, was south-westerly.

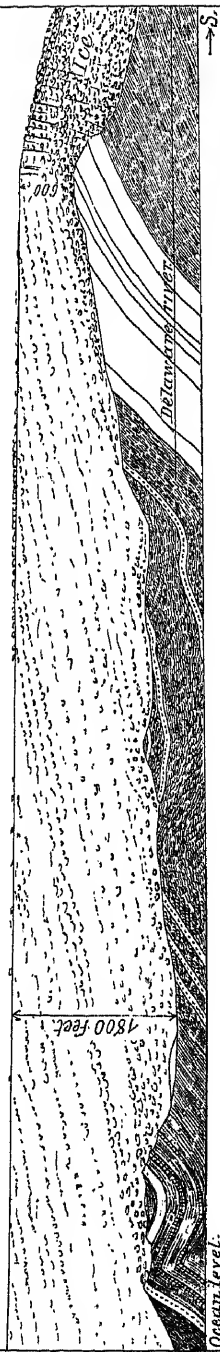
Striæ bearing S. W. are seen on the summits of the Laurentians, the Catskills, and the Alleghenies. Striæ with similar direction run from Hudson's Bay to Dakota. Exposed rock surfaces in Michigan, Wisconsin, and Minnesota show S. W. striæ. But near the edge of the ice-sheet the striæ always bear outwards towards that edge. Thus throughout eastern New England the striæ bear S. E. towards the ocean, close to the shore of which was the edge of the ice-sheet. So, too, in western Pennsylvania and eastern Ohio the striæ run S. E. towards the terminal moraine. In Wisconsin and adjoining States it has been shown that the striæ radiate in a fan-shaped manner toward the borders of great lobes of the glacier which at one time formed its southern extension.

Exceptional deviations in the course of striæ are due to local causes. The bottom strata of the ice followed the course of the valleys through which it flowed. Thus while the striæ of the Hudson valley from Lake Champlain to New York City are southerly, those on the bordering mountain ranges have the normal south-west direction. In Pennsylvania, as will be seen hereafter, the striæ in a valley are sometimes at high angles to those on the summit of a mountain. Such low-level striæ may have been made later in the history of the glacier than those made on elevated land, and been due to local glaciers which remained after the general ice-sheet had disappeared. The high-level striæ, which are uniform over large districts, are the only ones which indicate the general flow of the glacier at the time of its greatest extension.

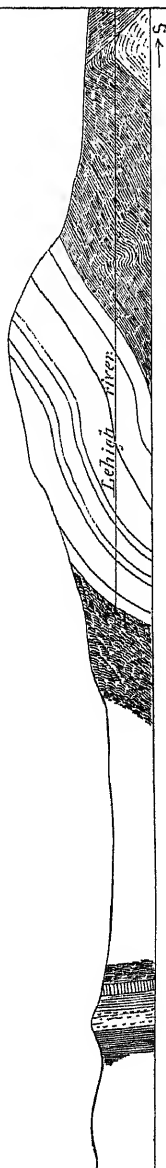
Similar evidence of their direction of transport is offered by the transported boulders.

In Western Pennsylvania, and throughout Ohio, boulders of Canadian granite, carried often a hundred miles from

*Transverse section of Godfrey's Ridge, Cherry valley and Kittatinny mountain,
at the Delaware water gap, showing the probable height of the ice.*



*Transverse section of the Devils wall, Aquanichicola valley and Kittatinny mtn.
at Lehigh water gap, in the unglaciated region.*



Mountain sections by H.M. Chance.

J. F. Lesley

their source, are found in great numbers. In Iowa and Wisconsin fragments of native copper have been found, some of which were transported over four hundred miles. A transportation of boulders as far as seven hundred miles has been reported from the Lake of the Woods.

Such instances of distant transportation occur where the flow of the glacial stream was most unobstructed, and where the striæ indicate a continuous movement. But where a succession of mountains or a continuous rise of ground obstructed the flow of the ice-sheet the far-traveled boulders were intercepted, and the glacial drift south of such localities contains, for the most part, locally derived stones. Thus in New England and in Eastern Pennsylvania far-traveled boulders are extremely scarce, ten to twenty miles being the usual limit of transport.

From the occurrence of striated rock surfaces and of transported boulders at high elevations, as well as from considerations dependent upon the movement of the ice-sheet, attempts have been made to calculate its thickness at various points.

As will be more clearly demonstrated by a detailed description of the glacial phenomena along the southern limit of the ice-sheet in Pennsylvania, the extreme edge of the ice *in certain valleys* was about 700 feet thick, becoming nearly double that thickness within a mile of its edge; and five miles back from the edge it was at least 1000 feet thick.

Where the edge of the ice was diagonal to the trend of the Pennsylvania mountains the intermediate valleys must have been filled with ice to a height exceeding the height of their bounding mountains, over the tops of which also the ice lay.

Thus in Monroe county the ice near Stroudsburg, 8 miles back from its edge at lakes Poconoming and Mineola, must have had a thickness measured thus:—Height of Blue Mtn. on the south-east, 1500' A. T.+Height of Pocono Mtn. on the north-west, 2000' A. T. divided by 2=*minimum* height of ice over Stroudsburg, 1750' A. T.; and this—height of present surface at Stroudsburg, 435' A. T.=*minimum* thickness of ice at Stroudsburg, 1225'; to which must

be added whatever thickness the ice had on the mountain tops at an equal distance back from its edge. It is therefore evident that the glacier at Stroudsburg (say 8 miles back from its edge in the valley) was 2000 feet thick. (See map and section facing page 1.)

A still more satisfactory demonstration of the vast thickness of the ice sheet at no great distance back from its southern edge is afforded by the marks which it has left upon the highest summit of the Wyoming mountain, overlooking Wilkesbarre, known as Penobscot Knob. The rocky top of the knob is well striated; and a large erratic boulder is perched upon it, at an elevation of 2200' A. T.; commanding a panoramic view of ten counties. Beneath it, on the north, lies spread out the Wyoming valley, glaciated everywhere; through which the Susquehanna river flows at only 530' A. T.

The difference ($2220' - 530' = 1710'$) gives the *minimum* thickness of the ice over Wilkesbarre. Evidently, it must have been at least 2500' thick to flow over Penobscot Knob and eight miles further southward to the terminal moraine in Conyngham valley.

The inclination of the surface of the glacier was steep near the margin, but very gentle farther back from it. Nothing is certainly known of the actual height of the surface of the main body of the ice; but since it flowed from Lake Ontario southward up the slope of southern New York, and reached the highest summits of northern Pennsylvania, 2500' A. T., its thickness in the centre of the lake basin must have been at least 3000 and may have exceeded 4000 feet. The discovery of transported boulders upon the summit of Mount Washington, which rises some 5000 feet above the surrounding region, shows that, at the time of the greatest extension of the glacier, that mountain and the whole of New England was buried beneath an ice-sheet at some places a mile in depth.

The highest peaks of the Catskill mountains, and isolated summits like Mt. Ararat in north-eastern Pennsylvania, seem to have stood up as islands, just as now in the great inland glacier of Greenland a few such isolated rock

masses form islands in a sea of ice.* But mountains in New England near the sea coast more than 2000 feet in height are striated to their very summits, and were clearly overtopped by the ice.

From the fact that the glacier passed over successive mountain ranges lying athwart its course without swerving from its general direction, as is clearly shown both in New England and in Pennsylvania, it is inferred that the ice must have been much higher than those mountains. Similar evidence of great depth is afforded in the continuous flow of the glacier from the Laurentians of Canada across the depressions now occupied by the great lakes to the Ohio river—a flow which, if we grant a continuous slope of the ice surface from the north, would require a great depth of ice in that region. The glacial phenomena in Pennsylvania, about to be described, prove that the onward flow of the glacier was continuous and united, and that topographical features did not influence the motion of its upper strata. They prove also that, unlike the separate glacial streams of Europe radiating from different centers, the American ice-sheet was united and massive, flowing onward as a frozen sea, though dividing into lobes near its edge; but many problems connected with its motion, its origin, and its cause are yet unsolved.

Further considerations upon the glaciation of North America are deferred until a description of the facts observed by the author in Pennsylvania has been given in detail. Numerous as have been the treatises upon the phenomena of the great ice age, facts are still greatly needed upon which to found more precise theories concerning the glaciation of this country. Sound generalizations can be drawn only after a most extended series of observations.

Pennsylvania happens to be most fortunately placed for

*The Catskill peaks rise to 4000' and even 4500' A. T., as measured by the late Prof. A. Guyot who found no *striae* on them. Prof. I. C. White reports (in G⁵, page 158) that he could find no *striae* and no remains of *drift* on the two isolated peaks of Mt. Ararat (2600' A. T.) and Sugar Loaf (2450' A. T.) in Preston township, Wayne county, Pa., although the whole surrounding country is glaciated at a general elevation of 2000' A. T.

the elucidation of the many problems of the great ice age. Occupying a middle position between the glaciated and the non-glaciated regions of this country, and between the well-studied glacial phenomena of New England and the imperfectly understood surface deposits of the west, and being traversed by the whole Appalachian range of mountains lying transversely to the ice flow, this State, so remarkable for its varied topographical features, is a typical region for the study of the Northern Drift, and offers unexampled facilities for laying true foundations of the science. Nowhere in the world has the great glacier come to an end and pushed out its terminal moraines under more varying conditions. From the lowlands of the Atlantic coast to the mountain plateau of the Alleghenies and down again toward the great plains of the Mississippi basin, the line can be traced, step by step, without a break, marking the extreme edge of the ice-sheet. Rivers flow out from the glacier, rivers flow back under it, and other rivers take their source south of it, and each have their distinctive accompanying phenomena full of interest and instruction. As from an industrial and political standpoint, so from its position in relation to the great glacier, Pennsylvania is the "Keystone State."

CHAPTER II.

The Glaciated Area of Pennsylvania.

The importance of knowing precisely what portion of the State has been covered by the ice sheet and what portion has not been so covered, cannot be too clearly set forth. In any geological investigation the subject of first importance is the construction of a geological map showing the limits of the formations, and no sound theories can be framed until such map is completed. So, too, for the successful pursuit of mining or of other practical enterprises, a map of the district is an acknowledged necessity.

Our knowledge of the most interesting period of geological history—the Quaternary Period—closely connected with the history of the human race, would not be so vague and uncertain, and students would not be distracted by so many contradictory views concerning it, had an accurate map of the glaciated area of the world been constructed. It is to the discredit of modern science that no such map exists. Except in a few limited districts, the edge of the glaciated area has not been accurately mapped. For want of such a map one hears of supposed proofs of glacial action in Delaware, in the Southern States, and even in the tropics; and often finds that some unusual mountain topography, valley sculpture, or remarkable patch of gravel, no matter where occurring, is referred to glacial action in regions never invaded, so far as we know, by any glacier.

(17 Z.)

But not only to the geologist but to the historian and antiquary is a map of the glaciated area important. Archaeological discoveries in the river gravels, dealing with the history and origin of primeval man and the time of his first appearance, depend directly upon an exact geological knowledge of these gravels, which in turn depends on a knowledge of the extent, the conditions, and the time of the glacier.

To the engineer, the miner, and the farmer too, a knowledge of the extent of the glaciated area is important. Many topographical changes, the filling up of valleys, the formation of terraces, the covering over of rocks, the arrangement of water supply, have been effected by glacial action; while the burying of mineral resources and the covering of soil brought to an otherwise barren land, so that land north of the terminal moraine is worth more per acre to the farmer and less to the miner than land south of it—these matters of practical economy are directly connected with the agencies of the glacial epoch and will be benefited by explorations intended to make our knowledge of that epoch more exact.

In Pennsylvania more than elsewhere special interest is attached to the definition of the glaciated area.

The distinction between the glaciated and nonglaciated regions of the State is very marked.

Although the general topography of the two regions is alike, the superficial features due to glacial agencies, the far-traveled and scratched boulders, the smoothed and striated rock exposures, the unstratified deposit of impure clay filled irregularly with both round and sharp stones which has been called *till*, the long *hummocky ridges* of stratified sand and gravel known as *kames*, and especially the numerous glacier-scratched fragments and pebbles—all these phenomena are in strong contrast with those of the nonglaciated country, where all the gravels are stratified and the pebbles water-worn; where the rocks are never polished or striated, but on the other hand often decomposed to a great depth; and where, except near the sea coast, wide stretches of the more elevated regions are perfectly free from *drift*.

Thus the surface deposits of Pennsylvania, however formed, may be divided into two great classes—those occurring in the glaciated area of the State, and those lying south of that area. This division is more satisfactory than the usual one of *stratified* and *unstratified*, since both of these varieties occur universally *together* in the glaciated region, and sometimes out of it, and both may be of contemporaneous age and of similar origin. The idea that unstratified drift is necessarily of immediate glacial origin, has led to more than one mistake.

The drift deposits of the *first class* may be divided into those made by ice, and those made by water.

The drift deposits of the *second class* may be divided into those of fluvatile, and those of oceanic origin.

In both classes of deposits their relative elevation above tide is a notable feature, serving in many cases to mark important distinctions both as to age and origin.*

The two classes of surface deposits meet one another in such river valleys as pass from the glaciated into the non-glaciated region; and it is in such valleys that the relation of the two classes of deposits to one another may be most satisfactorily studied. On high ground the glacial deposits frequently come to a sudden termination, no trace of *drift* lying to the south. But in certain river valleys the change from a glacial to an aqueous formation and the correlation in time of the deposits of the glaciated and unglaciated region is clearly set forth.

Of all the rivers which connect the two regions the Delaware is the most typical. Having its source far back in the glaciated area, where local glaciers continued long after the withdrawal of the ice-sheet, all the attendant phenomena of glacial action are finely exhibited in its upper portion; while in its lower portion, south of all glacial action, not only are there various river gravels and clays apparently representing successive floods, but, a series of oceanic gravels of pre-glacial age occur upon its banks, at various eleva-

*The elevations given in this report were obtained by aneroid barometer, using railroad levels as data.

tions, which themselves have been in part restratified in later times.

In the vicinity of Philadelphia, for example, the surface of the ground for a distance of four or five miles back from the Delaware river, and to a height of about 175 feet above it, consists of a deposit of clay, gravel, or sand, covering over the rocks as a sheet which is continuous except where eroded away by streams or other causes. These surface deposits are all stratified horizontally, and often show wave-action. The sand near the river is a true river sand; and the clays farther back contain rounded pebbles and water-worn boulders. These deposits cease at a fixed elevation above the river, being bounded by a line of hills which the writer has called the "*Upland Terrace*."*

Back of the Upland Terrace, which is approximately parallel with the river, the soil is made exclusively of decomposed rock, and no gravel or other signs of water-action are seen, except a few isolated remnants of an ancient ocean beach which cap certain hills bordering the Cretaceous and Tertiary deposits of the Atlantic coast.†

From the fact that decomposed rock lies beneath these drift deposits (as can be well seen at Gray's Ferry) and that portions of this decomposed rock are often taken up and re-stratified with the lower strata of the gravel, as well as from the absence of striated rock surfaces or pebbles, it is evident that a glacier was not here the agent of deposit.

Ascending the Delaware the materials of the *drift* become coarser further and further north. The *river sand* which at Philadelphia is a fine-grained and inconspicuous formation, for the most part filling the once deeper river channel, rises at Trenton 50 feet above the river and contains large boulders and many beds of coarse gravel. This deposit, which the writer has designated the "*Trenton gravel*,"‡ acquires special importance at this place on ac-

* The Surface Geology of Philadelphia and vicinity. Proc. Acad. Nat. Sc., Phila., Nov. 25, 1878.

† This "*Bryn Mawr Gravel*" with the other aqueous deposits of Southern Pennsylvania will be described in full in Report Z².

‡ The Trenton Gravel and its Relation to the Antiquity of Man. Proc. A. N. S. Phila. 1880.

count of the reported discovery in it of rude stone implements of palæolithic type, indicating the existence of man at the time of its deposition. As will be shown in Report Z', this gravel belongs to the time immediately following the final retreat of the glacier, and, therefore, is important in any inquiries which bear upon the time of that event.

In like manner the *brick-clay* contains more and more boulders and larger ones the further north it is examined. At Bethlehem and along the Lehigh, the stones in the clay are so numerous that it has in some places been mistaken for true glacial deposits, and, where the stones are thickest, for glacial moraines. Yet the deposit is still truly stratified, the stones water-worn, and the whole formation confined to the river valley and to levels not more than 180 feet above it.

Upon reaching Belvidere, an important change occurs in the surface deposits. The *Trenton gravel*, while retaining its general characters, is spread out to form a wide plain, and in the neighborhood of Stroudsburg to form a series of beautiful *terraces* rising successively one above the other. The formation is no longer confined to the river valley, but is joined at numerous points by confluent streams of similar sandy gravels, representing as many ancient water-courses, and elevated far above the level of the river. Most of the valleys, even those of small size, are deeply buried by these stratified gravels, which consist principally of the underlying rock worn into pebbles; and it becomes evident that some extraordinary source for such an unusual deposit of gravel must be sought for. In many valleys the sandy gravel rises in the centre in the form of a ridge, or a chain-like series of low rounded hills (*kames*), which are unlike anything occurring south of the glaciated region.

As to the second formation, the boulder-bearing *brick-clay*, a still more remarkable change occurs at Belvidere. Losing completely its stratified character, it becomes a heterogeneous mixture of impure yellow clay, filled with both rounded and sharp stones, which are imbedded at all angles in the clay, and are frequently striated or ground down on their longer sides. Boulders are much more frequent in

it and larger than they were south of Belvidere, and angular fragments of rock for the first time appear. But the most remarkable change is as to the limits within which the formation is confined. No longer bounded by a fixed elevation above the river, it occupies the hill tops as well as the valleys, covering the whole region to the north as though with a mantle.

Even on mountain summits this formation is represented by transported boulders. The writer found a boulder of Helderberg limestone perched upon the summit of the Kittatinny mountain, which had been lifted more than 1000 feet above its natural outcrop. Another boulder of the same limestone 20 feet long lies on the south side of the mountain, having been carried over its crest and several miles beyond. Another boulder of syenite occurring in that vicinity has traveled 150+ miles from the Adirondack region.

The *brick-clay* has in fact become a boulder-clay or *till*, having all the character of the "Northern Drift," or of the ground moraine of a glacier, as described in the introductory chapter.

In addition to this the underlying rock surface, no longer decomposed, is smoothed off, planed down and often striated with long grooves running in a southerly direction. No trace of such phenomena occurs in the country to the south of the glaciated area.

While the deposits of the two regions are thus continuously connected, the distinction between them is marked and unmistakable.

Similar phenomena may be seen on the east branch of the Susquehanna, the west branch of that river not entering the glaciated region. The *sandy river gravel* is an inconspicuous deposit until the vicinity of Berwick is reached; then, suddenly, it rises to form a fan-shaped flat-topped terrace plain, making an embankment 50 feet high; and at the same time the clays, which further back from the river and at a higher elevation have thus far formed a shallow deposit are now succeeded by true *unstratified till* filled with glaciated fragments and heaped up into peculiar rounded hummocks, with a topographical character quite unlike anything lower down the river.

Perhaps the best example of the transition from the one class of deposits into the other is shown on the Conewango river where, as the glaciated region is approached, the river gravels become heaped up into ridges, and occasionally contain pebbles showing traces of glacial striations which have been only partially worn off by the action of water. Yet, as in the other cases, the point where the deposits of truly glacial origin begin and the river gravels end is clearly marked both by internal and by topographical characters.

The writer has explored every river and stream which flows out of the glaciated region, and finds in each case a distinct point of demarkation between the *glaciated* and *non-glaciated regions*. Sometimes the river shows by its very aspect and rate of motion the influence of glacial agencies, its channel being so filled up with glacial débris as to render its flow sluggish. Still more evident is it in the case of tributary streams, which often flow on rock bottoms in the unglaciated region, while in the glaciated area their channels may be deeply buried under *drift*. The tributary streams of the Lehigh north of the terminal moraine are in marked contrast to those south of that point; the former flowing through drift-filled ravines with gentle banks, the latter through rocky precipitous gorges. The Conewango in the glaciated area is a sluggish stream, flowing upon drift and bordered by low gravel banks; while south of the terminal moraine its banks are rocky and steep.

An important fact gained from a study of these rivers is, that the southern limit of glaciation in them is identical with that in the highlands; and a line connecting the limits of glaciation as determined in the valleys is the same as that connecting similar points in the highlands. The opinion that separate glaciers ran down each river valley like a series of tongues projecting from the united glacier is not sustained by these observations.

Nor does the idea that there was a sort of universal deluge at the time of the final melting of the ice-sheet receive support from these investigations, which go to show that the floods due to that cause were entirely limited to the separate river valleys and to the immediate lowlands, or to

similar well-defined but now extinct water-courses. This will be more fully shown in Report Z².

The Till.

The general character of *till* as distinguished from water-formed clays has been already described. Its most distinguishing feature is the presence of scratched or striated stones, which with rare exceptions never occur outside the glaciated area. Indeed as a rule the finding of a striated pebble in an unstratified deposit is presumptive evidence of its being of glacial origin. Although *till* is not universally present its distribution is without regard to any lines of drainage. It frequently lies upon the very summits of mountains, as for example on the Pocono plateau, and throughout the Allegheny mountain region in Lycoming and Sullivan counties, 2000' to 2500' A. T.

An excellent section of *till* is presented by the photographic picture Plate IV, representing a fresh exposure on top of the Bangor slate quarries, and exhibiting the confused mingling of earth and stones of varied shapes and sizes.

The stones in the *till* have frequently a peculiar shape characteristic of ice action, showing a planing and striation on their sides, while rough at the ends. (See photographic picture Plate V.) The striations upon the pebbles and boulders are mostly parallel to the longer diameter of the stone; but on a circular stone they cross each other in all directions. They have evidently been ground against one another or have been pushed over a rock surface by the motion of the glacier.

The *till* varies in depth from a mere sprinkling of boulders, by which it is sometimes represented, to a depth of 100 feet or more. In north-western Pennsylvania it is in many places 200 ft. deep. In more western States it is still deeper, a depth of 300 feet having been reported in certain parts of Indiana. In eastern Pennsylvania, perhaps on account of the inequality of the surface and the numerous mountain ranges, it is seldom deep and on many mountain sides is completely absent.

Where a deep cut exposes a fine section of *till*, as at

Sharpsville, Mercer Co., the lower portion is seen to be much more compact than the upper part, and of a bluish color. This is probably the original condition of the deposit before being loosened and oxidized by atmospheric agencies.

The *till* in eastern Pennsylvania is usually abundant at the heads of valleys and in other slight depressions, and is more abundant in valleys on the north side of a mountain range than on the south side.

The origin of *till* has been explained in several ways, some holding that it is a ground moraine formed underneath the glaciers by its grinding and abrasive action; some believing that large portions of it were dropped from the end of the glacier as it melted; and others that it was formed of material beneath the glacier but deposited mainly near its margin where the ice was less deep. The last view is probably more correct, for the upper portions of the *till*, which, especially in the Western States, frequently show water-action. The *till* is in great part composed of local material, varying in composition with the geological character of the region. The far transported boulders lie very frequently at or near the surface of the till, as though dropped upon it from the upper ice.* From the fact that the high summits in Pennsylvania are rarely capped by *till*, but on the other hand often hold far transported boulders, it is inferred that the upper portions of the glacier were clean, bearing only occasional boulders derived from a distance; while the bottom of the glacier was continually grinding up the underlying rock and filling itself with the *débris*.

The origin of the Philadelphia brick-clays may be found perhaps in the muddy water which issued from the grinding base of the glacier.

Where the glacier sent out lobes across a low country, or where it crossed a great river valley, the *till* gives the strongest evidence of sub-glacial water-action. The stratified drift deposits of the great Mississippi valley and the subaqueous

* The great number of erratics seen in some places on the surface of the *till* may be partly explained by the partial removal of the mass and concentration of the blocks.

till of the St. Lawrence valley* indicate the presence of quantities of water circulating beneath the ice in those regions; but it cannot be too strongly insisted upon that the *till* occurring in the mountainous districts of Pennsylvania is unstratified and destitute of any trace of aqueous action.

Moraines.

An eminent geologist has asserted that "most if not all the detrital material of North America is destitute of any true morainic character."† Whether this statement be correct or incorrect for other regions of the continent, a belt of *typical moraine deposits* certainly extends the entire length of Pennsylvania.

As first studied in Switzerland moraines were defined as unstratified heaps of rock *débris* (angular and rounded) arranged either along the margins of a glacier or along the middle contact line of confluent glaciers.

Thus *terminal*, *lateral* and *medial* moraines may occur on the same glacier, the latter often stretching down from its source in the *névé*. The material forming the moraines in Switzerland is in great part derived from the falling of stones from the cliffs bordering the glaciers or from the detaching of such stones by the ice. The material in both cases is borne along on the surface of the glacier and either pushed out at its edges to form a lateral moraine or finally dumped at its end as a terminal moraine. The character and size of these moraines vary with the size of the glacier and its position. Since the detritus is largely derived from bordering cliffs the *relative* size of the moraine diminishes with the increasing breadth of the glacier.

But there is another source whence the Swiss glaciers derive a portion of the detritus now seen at their base. Not only does the glacier bear stones dropped on its surface, but by virtue of its motion it grinds and polishes *beneath it* masses of rubbish abraded from the bed over which it

* At Montreal the *till* rests upon glaciated rock surfaces but is nevertheless full of marine shell, sponge specules, &c., and has evidently been made under water.

† Whitney's Climatic Changes, p. 5.

moves. This basal *débris* is rolled and striated and rounded to a far greater degree than the uneven and angular surface material. The term *moraine profonde* or ground moraine has been given to the material thus pushed along beneath the glacier. When the glacier is advancing over ground already before occupied by ice it pushes up a portion of the older ground moraine, which, mingling with the more angular *débris* now dropping from its surface, constitutes a new terminal moraine when it again ceases to advance.*

It is evident that when dealing with a glacier of the proportions indicated by the ice-sheet of North-eastern America, where projecting or bordering cliffs were probably wholly unknown (except in its growth and decline) some representative of ground moraine is alone to be sought. But as has already been stated, the *till* fulfills all the conditions of a *ground moraine*. The terminal moraines of an extended ice-sheet composed in great part of this ground moraine should be less angular than the terminal moraines of smaller glaciers bordered by cliffs.

Accordingly we find that the great ridges of drift which are regarded as the terminal moraines of the North American ice-sheet, are largely composed of rounded and striated pebbles, angular fragments being scarce. On the other hand, angular *débris* is characteristic of the smaller moraines which were formed by the local glaciers remaining after the greater part of the ice-sheet had withdrawn.

Moraines of this character occur at many places in the White Mountains†; and the author has observed such among the Catskills and among the mountains of eastern Pennsylvania, and called them "mountain moraines."

The *terminal moraine of a continental ice-sheet* should in the nature of things be small and often inconspicuous. It should consist mainly of glaciated material; and it should by its contours and by its position be such as a glacier alone could produce. All these conditions are fulfilled by the lines of drift hills which constitute the terminal moraine in Pennsylvania. The peculiar topography characterizing

* An excellent description of Swiss moraines is given in the Annual Report of the Wisconsin Geological Survey for 1878.

† See Geol. of N. H. Vol. III.

these hills—a succession of conical *hummocks* and *kettle-holes*—is a topography unlike that produced either by wave action, or by aerial erosion; while on the other hand it is identical with that characterizing the moraines of modern Swiss glaciers.*

There is another class of moraines which, probably formed during the northward retreat of the ice-sheet at points where it halted or again advanced for a time, occur at many places in the glaciated area and have been called by Professor Cook *moraines of recession*. These have the same character as the terminal moraine and are sometimes more largely developed.

The most important proof of the morainic character of much of the drift deposits of America lies in the fact that the ridges regarded as terminal moraines lie at right angles to the glacial striae, and this is true for both mountainous districts and for the lowlands. That this is true for Pennsylvania will be evident after a description of the facts.

Connected with the subject of moraines are certain elliptical hills of drift which, composed throughout of very compact *till*, occur in certain regions of the glaciated area and were called by Professor Hitchcock *lenticular hills*. These curious hills—particularly abundant in Massachusetts, especially in the vicinity of Boston—perhaps represent moraines (or at least large accumulations of drift) which have been overridden by a later advance of the glacier. Although perfectly unstratified, and filled with glaciated fragments, they frequently show lamination on a large scale, as if layer after layer of *till* had been pushed along and packed down by the advance of the superincumbent glacier. These lenticular hills appear to be in all respects similar to the *drumlins* of Great Britain.† They lie generally some distance back from the edge of the glaciated area. They have a smooth, rounded contour, and vary in size from a few hundred feet to half mile in length, with

*See Prof. Desor's special memoir on the moraine region of the lake of Thun.

†See an excellent paper on the glaciation of Iar Connaught by Kinahan & Close.

usually about half or two thirds as great width, and with heights varying from 50 to 150 feet.* They have also been called *mammillary hills*. One of these drumlins in Mercer county, is described farther on in this report; and doubtless many others occur in other portions of the glaciated area of the State.

Moraine lakes, or ponds.

Closely connected with the distribution of the *till* and the formation of moraines is the occurrence of numerous *lakes* throughout the glaciated district. On account of the unequal distribution of the *drift*, water-courses have been dammed up, lines of drainage have been altered, and numerous lakes and swamps have been formed in the inequalities of the surface.

The occurrence of lakes is one of the most characteristic features of the glaciated area of the United States. A hundred thousand exist back of the terminal moraine, and almost none in front of it. So surely do a multitude of lakes indicate former glaciation that it is possible to define the glaciated area of any region in a general way simply by glancing at a good geographical map and dividing the *lake* from the *lakeless* regions. In Wisconsin there are 2000 lakes and many more marshes (which represent extinct lakes) back of the "Kettle moraine," and not one in front of it. In Pennsylvania and New Jersey back of the terminal moraine the number is scarcely less; but in front of it there is not one.

The abundance of lakes in the region covered by the "Northern Drift" was noticed long ago, and they were at first ascribed to the eroding force of the ice, under the supposition that they were scooped out in the solid rock; but facts suffice to indicate that their origin is due to filling up rather than to scooping out—to obstruction rather than to removal.

Two classes of lakes may be distinguished in the glaciated area of Pennsylvania.

* For a photograph of lenticular hills see Geol. of N. H., vol. ii, p. 288. For descriptions see Proc. Bost. Soc. Nat. Hist.; papers by Shaler, Hitchcock, Upham, Wright, &c.

The first of these two classes of lakes are due to the damming up of streams or choking up of the original drainage system by the irregular deposition of the drift. Sometimes it is a morainic ridge, sometimes merely a body of stratified drift, which has filled up a river course or prevented the free flow of the stream. Sometimes the terminal moraine itself has thus dammed up a stream, as in the case of Long Pond on the Pocono.

The second class are those lakes which with neither apparent inlet or outlet fill *kettle-holes* or similar depressions in the moraine itself. These occur at many points along the terminal moraine, even at the summit of a mountain, as for example Deep lake on the top of the Pocono mountain, (2120' A. T.) Depressions made when the moraine was created by the glacier serve as reservoirs into which water has flowed from the surrounding gravel. Lakes Poponoming and Minneola near the Wind Gap are of this character. Such lakes often have the peculiarity that they lie above the level of the surrounding country like the crater of a volcano.

The numerous swamps of the glaciated region are of similar origin, and are also of two kinds, either shallow or imperfectly formed lakes, or lakes partially drained by the deepening of their outlet.

That so many lakes are still not drained, although the gradual deepening of the outlet is now in progress, is one of the arguments in favor of the comparatively recent close of the glacial epoch.

Boulders.

The transported boulders or *erratics* which, often perched upon mountain summits far beyond the reach of any conceivable floods or floating icebergs, are such trust-worthy witnesses of glacial action, occur everywhere throughout the glaciated area of Pennsylvania, and in all cases can be traced to a more northern source. Sometimes, (as in the case of the boulder on Penobscot knob, shown in Pl. XVI,) they have been carried from one mountain to another across an intervening valley. Sometimes, as in the case of

the Helderberg boulder on the Kittatinny Mountain, they have been lifted from the valley to the top of a mountain 1000 feet higher. Sometimes, as witness the great limestone boulder north of Portland, they have been carried from one valley to another farther south after being lifted *across* a mountain range. And sometimes, as shown by the boulders of Adirondack syenite on the Pocono and near the Wind Gap, and as shown by the many boulders of Canadian granite in western Pennsylvania, they have been carried hundreds of miles before coming to their final resting place.

These boulders vary in size from a small pebble to masses hundreds of tons in weight. As a rule the farther the source from whence they were derived the more abrasion do they show. Thus the limestone blocks just referred to, which have traveled but a few miles, are quite sharp, while the boulders of Canadian granite so frequent in western Pennsylvania are well-rounded.

The direction of transport of boulders corresponds with the direction of the striae on the rock ledges, and in the case of far-traveled boulders more especially with those striae at high levels.

Boulders occur either isolated, or upon the *till*, or imbedded in it. When protected from the erosive action of the weather by being buried in *till* they very frequently show *striation*. (See Photographic Plate V.)

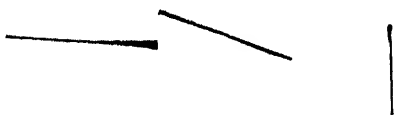
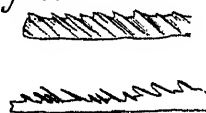
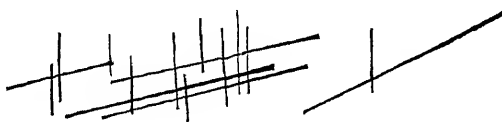
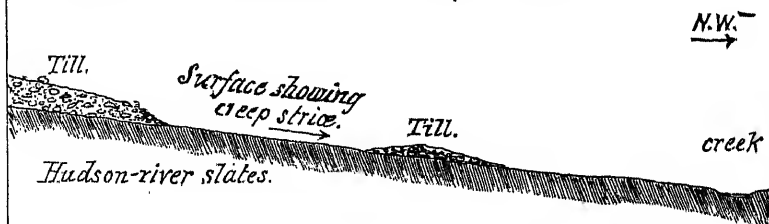
Neither as smoothly rounded as the pebbles of river gravel,—nor so angular as the frost-broken *débris* on a mountain side,—they exhibit rubbed and ground edges and surfaces quite characteristic of glacial action. The most typical examples occur in the lower hard blue *till*.*

Far traveled *erratics*, having been carried forward by the upper ice, seldom show fine striations. In the *till* of eastern Pennsylvania such granitic boulders number less than .01 per cent of the whole number; but in western Pennsylvania they amount to about .1 per cent.†

While boulders are more numerous near the line of the Moraine than elsewhere, there occasionally occurs just back

* Well exposed, e. g., in the Sharpsville cut, Mercer county.

† These Canadian *hard heads* are a notable feature of the glaciated region in the western counties.

*Glacial striae.**Fig. 1.**Fig. 2.**Fig. 3.**Fig. 4.**Fig. 5.**Fig. 6.**Fig. 7. Glacial striae crossed by creep striae.**Fig. 8. Formation of creep striae.*

of it a *strip of almost boulderless ground*. Future research may discover perhaps a loop-like arrangement of lines of boulders parallel with the loops of the terminal moraine, separated by belts destitute of or poor in boulders perhaps miles in width, marking stages in the retreat of the ice sheet.

Planing and Striation.

The decomposed rock so common in southern Pennsylvania is not seen in the northern portions of the State, the glacier having scraped it away. Everywhere where the *till* has been removed, hard, smooth and often polished surfaces of rock may be seen. Projecting crags are rounded off; and the direction of the glacial movement is frequently indicated by the greater smoothing of that side of a crag or ledge which sustained the impact by the ice; in other words, the northern side of such rocks are worn smooth while the southern side is often left jagged.

If these planed surfaces of rock are closely examined, especially if the soil has been lately removed, they will generally be found to be scored or scratched in a series of parallel lines or grooves (evidently the result of the movement of stones frozen into the bottom of the ice-sheet, or pushed along under it and acting as chisels or gouges) varying from the most minute scratch to deep grooves sometimes six feet wide. These *glacial striæ*, so far as observed in Pennsylvania, have universally a more or less southerly direction, varying in different localities to the east or west of south.

The *glacial striæ* of Pennsylvania present special features of interest, which will be reviewed more fully after the presentation of the facts. A great groove in Monroe county found by the author is 6 feet wide and 70 feet long (Plate XVI.) Some of the *striæ* are curiously-shaped gouges and often show the direction of glacial movement by the shape of the gouge. (See page plate 2, figs. 1, 5, 6.) Sometimes the *striæ* cross one another, a second set of *striæ* having been produced by a later movement of the glacier (Plate XVI.)

Fig. 1. Sketch map of kames at Ackermanville

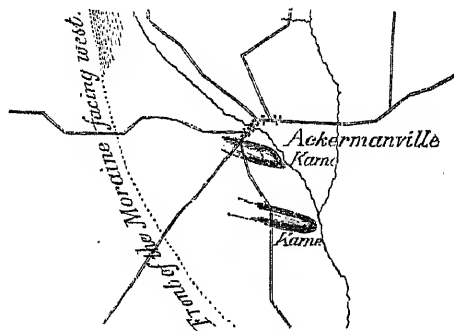


Fig. 2. Sketch section of kame at Ackermanville.



Fig. 3. Fault in a buried kame at Stroudsburg.

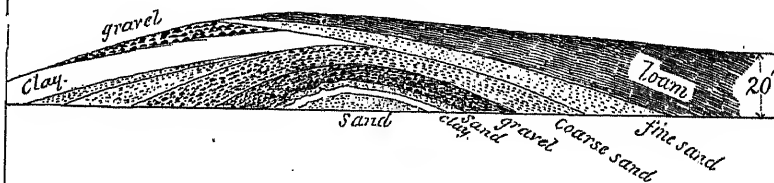


Fig. 4. Section of a valley filled with Drift from which projects the top of a Buried Kame



The striæ run up hill as well as down. While varying in direction in valleys, those upon the mountain tops maintain uniform directions throughout large districts, and thus record the movement of the ice-sheet as a whole.

A curious kind of striæ produced in post-glacial times by the sliding down hill of a body of *till* may be seen at several places in Pennsylvania. These I have called *creep-striæ*. (See Page plate 2, fig. 7.)

Kames.

Of the stratified deposits of the glaciated area the most important are those peculiar ridges of sand and gravel known as *kames*. These are narrow ridges of more or less regularity which, sometimes composed of a series of tortuous and reticulated ridges, sometimes simple, and frequently alternating with knob-like conical hills inclosing similar conical depressions, are always composed of *stratified water-worn gravel* of local origin, and generally lie along the centre of valleys and represent ancient water-courses.

These gravel ridges are often very steep — as steep as the nature of the material will allow. The gravel of which they are composed has often an *anticlinal structure* consisting of fine material below and coarse above. (See Page plate 3, fig. 2.)

They occur in the region of the Northern Drift both in Europe and America. They have been called *kames* in Scotland, *asar* or *osar* in Sweden and *eskers* in Ireland. The term *asar* is perhaps more properly applied to the long Scandinavian ridges and the equally long ridges which traverse Maine and other portions of New England; while the term *kame* may be limited to such short ridges near the terminal moraine as occur in Pennsylvania.

Various explanations have been offered to account for kames. Geikie at first thought that they were the result of marine action,* but afterwards† attributed their formation to sub-glacial rivers. Upham‡ regards them as due to

* Great Ice Age, 1st Ed. p. 228.

† 2d Ed. p. 217, &c.

‡ Geol. of N. H., Vol. III, p. 14.

rivers flowing on the surface of the ice and as being formed at the ice front during the retreat of the glacier; while Wright* believes that in many cases they are due to the sliding down from the surface of the ice of morainic débris accumulated near its end, so that they may represent medial moraines.

While the two latter theories may be true for the long asar of New England, which, starting sometimes 1500 feet above the sea, extend 150 miles, the short kames observed along the edge of the ice-sheet in Pennsylvania appear to be due in all cases to sub-glacial rivers.

Terraces.

Most of the river valleys of the glaciated area are bordered by one or more level-topped terraces made of horizontally stratified sand and gravel. These terraces record variations of the water level, both during and after the glacial epoch.

The terrace material forms the largest portion of the stratified drift, and being the latest of all the drift formations often covers over all other deposits. An example of a *kame buried beneath a terrace deposit* in Monroe county, Pa., will be described. The material forming the terraces is often known as *modified drift*, and is sometimes of great depth. It was derived in part from the melting glacier, in part from the till, at the close of the glacial period.† Since that time the rivers have been cutting through this stratified deposit and forming terraces at successive stages.

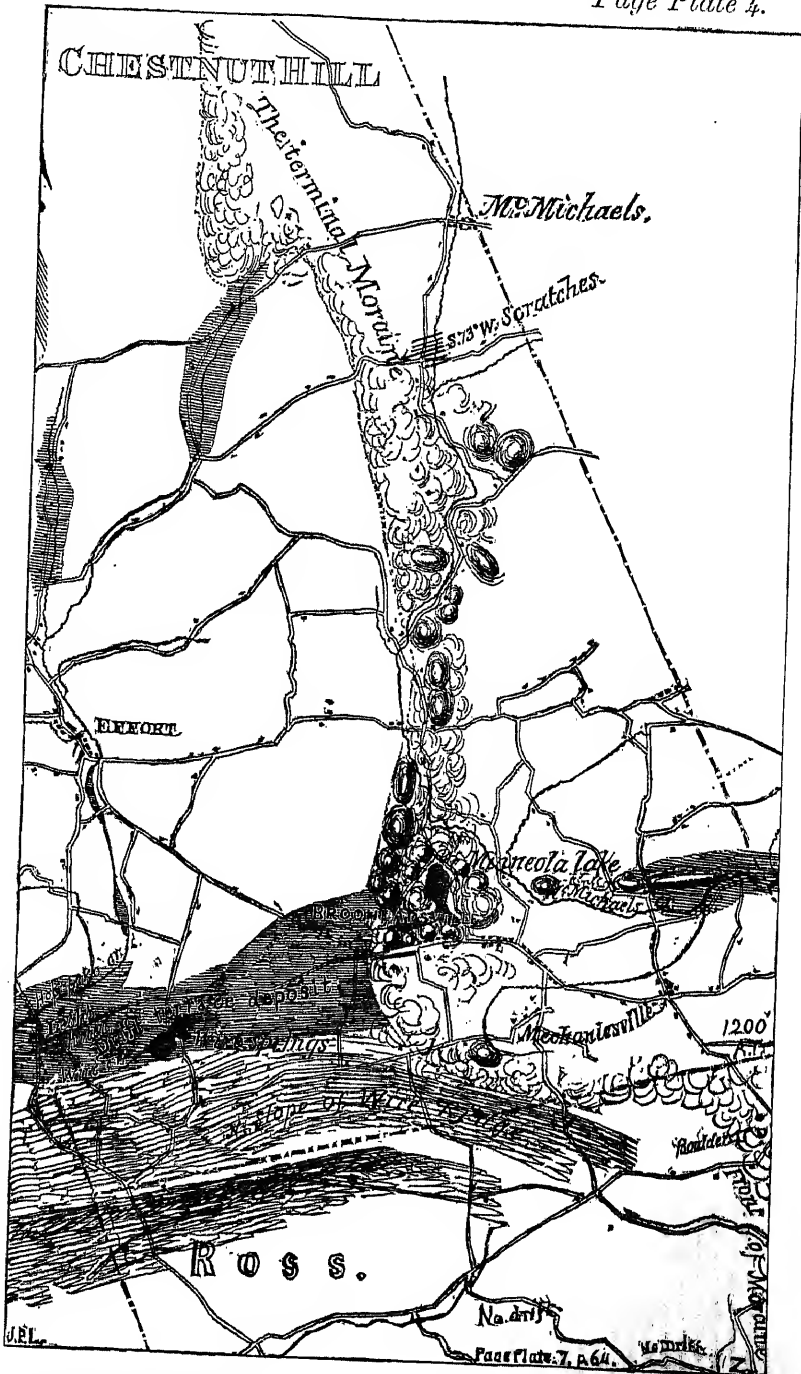
Some of the most beautiful terraces in the State occur in the vicinity of Stroudsburg where a series of five have been described by Prof. I. C. White, in Report G 6, 1882, pages 51, 269. The highest and farthest from the river, and the oldest, is at 500' A. T. or 115' above Brodhead's creek.

§ Proc. Bos. Soc. Nat. Hist., XX.

†The whole subject of stratified drift, and of a possible or probable glacial or post-glacial submergence of the continent, is still under discussion.

* For information on American Kames consult Stone on the Kames of Maine; Upham on the Kames of New Hampshire; Wright on the Kames of Massachusetts; Newberry on the Kames of Ohio; Dana & Upham on the Kames of the Connecticut Valley.

Under the name of *terrace-deltas* some curious delta-shaped deposits will be described which occur at the point where one flooded stream met another. The masses of gravel brought down by a smaller stream and spread out like a fan on meeting a larger stream, form a terrace considerably higher than could be produced by either one.



CHAPTER III.

The Great Terminal Moraine.

That the Northern Drift was deposited by a continental glacier rather than by ice-bergs is a settled fact, sufficiently proved by the *terminal moraine*.

Every modern glacier pushes up at its foot a ridge of detritus composed of rounded, angular and striated fragments of rock, which the ice has taken up at various points along its course and carried partly on top, partly below, to the point where the glacier comes to an end. It thus forms a *terminal moraine*, which may vary in elevation with the foot of the glacier, and on high ground may show no signs of water action.

Such a line is radically different from the level shore line of a body of water whose beach, even if non-fossiliferous and covered by ice-berg-borne boulders, is mainly composed of stratified water-worn pebbles, and has terrace-like features quite unlike the rounded hummocks and interlaced ridges of a true moraine.

The moraines of Lombardy mark the ancient southward extension of the glaciers of the Alps down to the plain of the Po.

The absence of terminal moraines in Norway and in Greenland may be accounted for by the former greater extension of the glaciers of these regions, whose moraines would be found if sought for out at sea.*

Large terminal moraines may be seen in several parts of the Rocky mountains; and these, sometimes several hundred feet high, furnish indisputable proofs of ancient gla-

*A supposed sub-marine moraine has recently been discovered connecting the Faroe islands with Scotland.

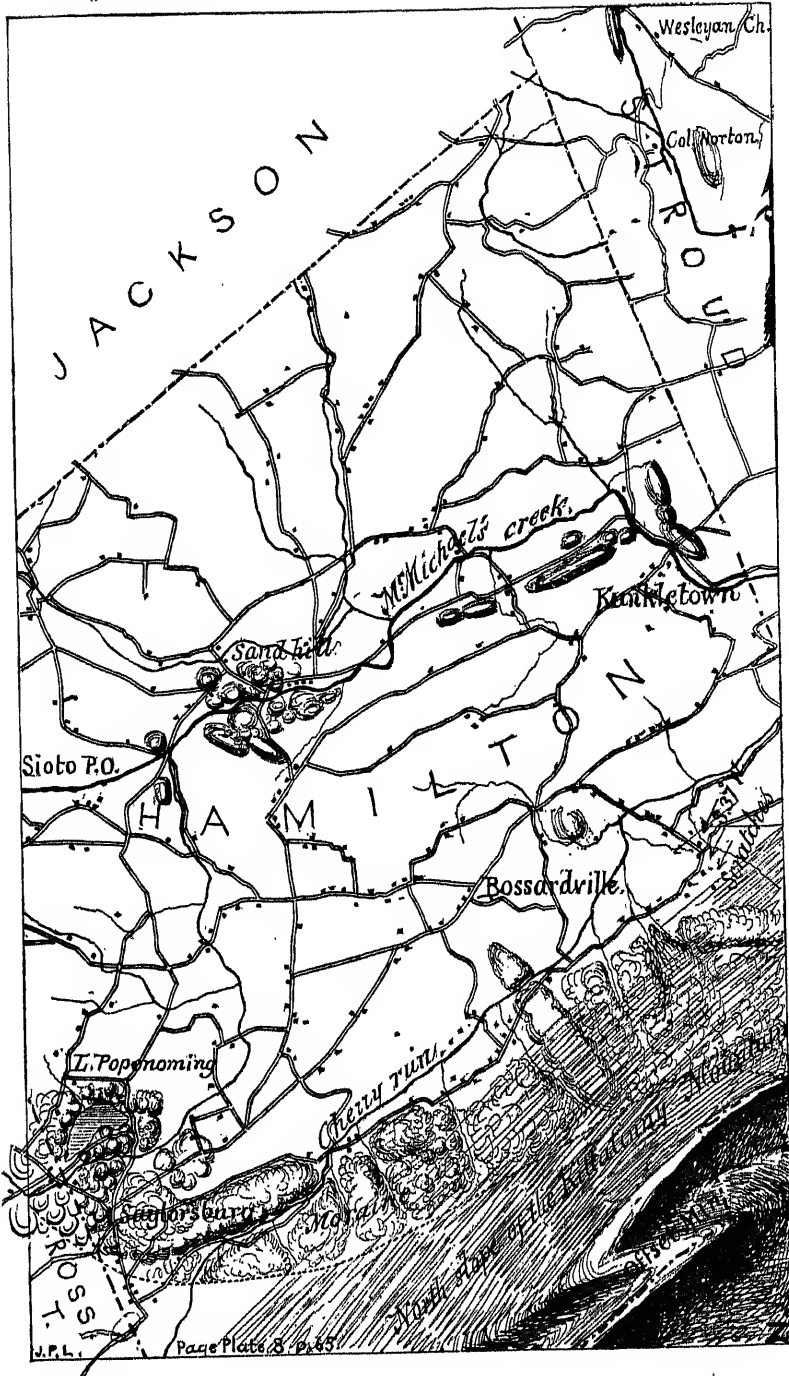
ciers. Moraines sometimes 350 feet in height, made up of angular *débris* and extending several miles out from the base of the mountains, occur along the Sierra Nevada. The moraines in the region of South Park, Colorado, are very striking glacial features and are even more conclusive than striæ or scratched boulders. In fact, a terminal moraine may be regarded as the one decisive proof of glaciation.

By the discovery therefore in Pennsylvania and in other portions of America of an immense terminal moraine, which, as a nearly continuous ridge of unstratified and glaciated material, crosses alike mountains and valleys, and forms everywhere on high land the boundary between the drift-covered and the driftless regions, the theory that the Northern Drift was deposited by a glacier of immense extent is entirely confirmed.

The idea that the great glacier of north-eastern America was bounded (at least at one stage of its extension) by a terminal moraine has long been entertained in a general way, but it is only within a few years that it has been actually demonstrated; and the lack of such a demonstration has been used as one argument against the existence of a continuous ice-sheet.

It has been suggested with some reason that great floods resulting from the melting of the ice would necessarily sweep away all traces of a moraine. It has been suggested that the boundary of the ice-sheet would be so irregular, owing to the formation of long fingers of ice down the principal river valleys, that it would be impossible to trace a continuous terminal moraine.

But the facts to be described in this report dispel the idea that the glacier was in any way prolonged down river valleys, or that floods at the time of its melting extended beyond the immediate vicinity of such valleys. They show that the edge of the glacier in Pennsylvania was a slightly undulating line, almost everywhere sharply defined, and marked by a continuous line of drift hills, which exhibit when typically developed characteristic contours identical with those of the more recent moraines of Alpine valleys and other glaciated regions.



By no ingenuity can this line of drift hills be construed into the shore-line of any body of water. Neither are its pebbles always water-worn; nor does it follow any fixed level. Varying in elevation from sea level to nearly 2600' A. T., and similar in its features throughout the whole of its course, it must be regarded as a true terminal moraine.

The investigations of Professors Cook and Smock in New Jersey, and of Mr. Upham in Long Island and Massachusetts, made in 1877, appear to have been the first to actually demonstrate the existence of a terminal moraine in the line of drift hills extending from Cape Cod through Woods Hole, and Block Island and Long Island to Brooklyn.

Mather had described the line of drift hills on Long Island as long ago as 1842, but did not recognize their significance.

Throughout this portion of its course so close to the ocean it was not possible to prove that it marked the extreme edge of the ice-sheet; but when it was shown that the same series of hills continued across New Jersey in a continuous line from Staten Island to Belvidere on the Delaware, and that in its winding course across the hills and valleys it everywhere divided the glaciated from the non-glaciated areas of New Jersey, its true meaning and character became evident.

Some time previously the observations of Professors Newberry, Winchell and Andrews in Ohio had showed that certain ridges running parallel to the shore of Lake Erie represented the margin of a lobe of the glacier in Ohio at one period during the glacial epoch. Mr. G. K. Gilbert in describing the ridges in the Maumee Valley regarded them as portions of a terminal moraine; and the observations of Professors Chamberlin, Irving and other members of the geological surveys of Wisconsin and Minnesota showed that certain irregular ridges of drift marked the halting places or oscillations of the glacier in its northward retreat through the north-western States.

In 1878 Prof. T. C. Chamberlain published an important paper "on the extent and significance of the Wisconsin Kettle Moraine" in which the characters of a great moraine

were pointed out and its conjectured course across the country sketched out. He showed that at one period (not necessarily that of the greatest extension of the glacier) great lobes of ice formed its southern boundary, and produced terminal moraines of great extent, forming noticeable features in the landscape. The "Leaf Hills" in Minnesota described by Winchell and Upham form the continuation of the "Kettle Range" of Wisconsin; while outside of these, forming an older terminal moraine, lies that remarkable feature of the Western prairies known as the *Coteau des Prairies*. Still farther north-west is an immense series of drift ridges sometimes 30 miles broad and two hundred feet high, which, heaped up upon the Cretaceous strata and 2500 feet above the sea, is known as the *Coteau de Missouri* and extends far up into British America to the headwaters of the Saskatchewan river.

Other explorations showed that these moraines probably formed a continuous series across the country; and investigations now in progress indicate a continuous moraine, disposed in a series of great loops extending from eastern Dakota through Iowa, Wisconsin, Indiana and Ohio and joining the moraine in Pennsylvania to be described. West of Pennsylvania scattered boulders and other drift extend for many miles in front of the line of drift hills constituting the moraine proper; but, unlike the moraine in Pennsylvania, the Western drift hills are largely composed of water worn materials, being probably similar to some of the kame-like sandy ridges found in northern Pennsylvania and central New York.

With the able assistance of Prof. G. F. Wright the author has been able to follow and define the southern limit of glaciation in Pennsylvania continuously across the State, in a line nearly 400 miles in length.

The line separating the glaciated from the non-glaciated regions is defined by a remarkable accumulation of unstratified drift material and boulders, which, heaped up into irregular hills and hollows over a strip of ground nearly a mile in width, forms a continuous line of drift hills (more or less marked) extending completely across the State. These

hills vary in height from a few feet up to 100 or 200 feet; and while in some places they are marked merely by an unusual collection of large transported boulders, at other places an immense accumulation forms a noteworthy feature of the landscape. When typically developed this accumulation is characterized by peculiar contours of its own,—a series of *hummocks*, or low conical hills, alternate short straight ridges, and inclosed shallow basin-shaped depressions, which like inverted *hummocks* in shape are known as *kettle holes*. Large boulders are scattered over the surface; and the unstratified *till* which composes the deposit is filled with glacier-scratched boulders and fragments of all sizes and shapes.

The average width of the moraine is about one mile.

At many places, however, the limit of glaciation is marked merely by an unusual collection of large transported boulders. This is especially the case in front of a high mountain range which has “combed out” the drift from the ice.

The peculiar topographical character of the moraine is one of its most constant features and while common to other deposits of glacial origin is not known outside the glaciated region. It cannot be explained as the result of aerial erosion but appears to have been originally given by glacial agencies and to have changed but slightly in appearance since the withdrawal of the ice-sheet.

The following characters apply to moraines of recession, and to kames, as well as to the terminal moraine, and are generally true for all portions of the glaciated area of America. In Pennsylvania it should be said these features are more clearly developed in the region north of the terminal moraine than in the moraine itself, perhaps because the former deposits are the more recent.

A complex series of *short winding ridges*, each of them narrow and steep, are interspersed among conical peaks, short spurs, mounds and hummocks, many of which are as steep as the drift will lie, and which together make an irregular and confused hilly region of undulating and generally graceful contours. Corresponding with the elevations are rounded or *elongated depressions* of variable depth, often

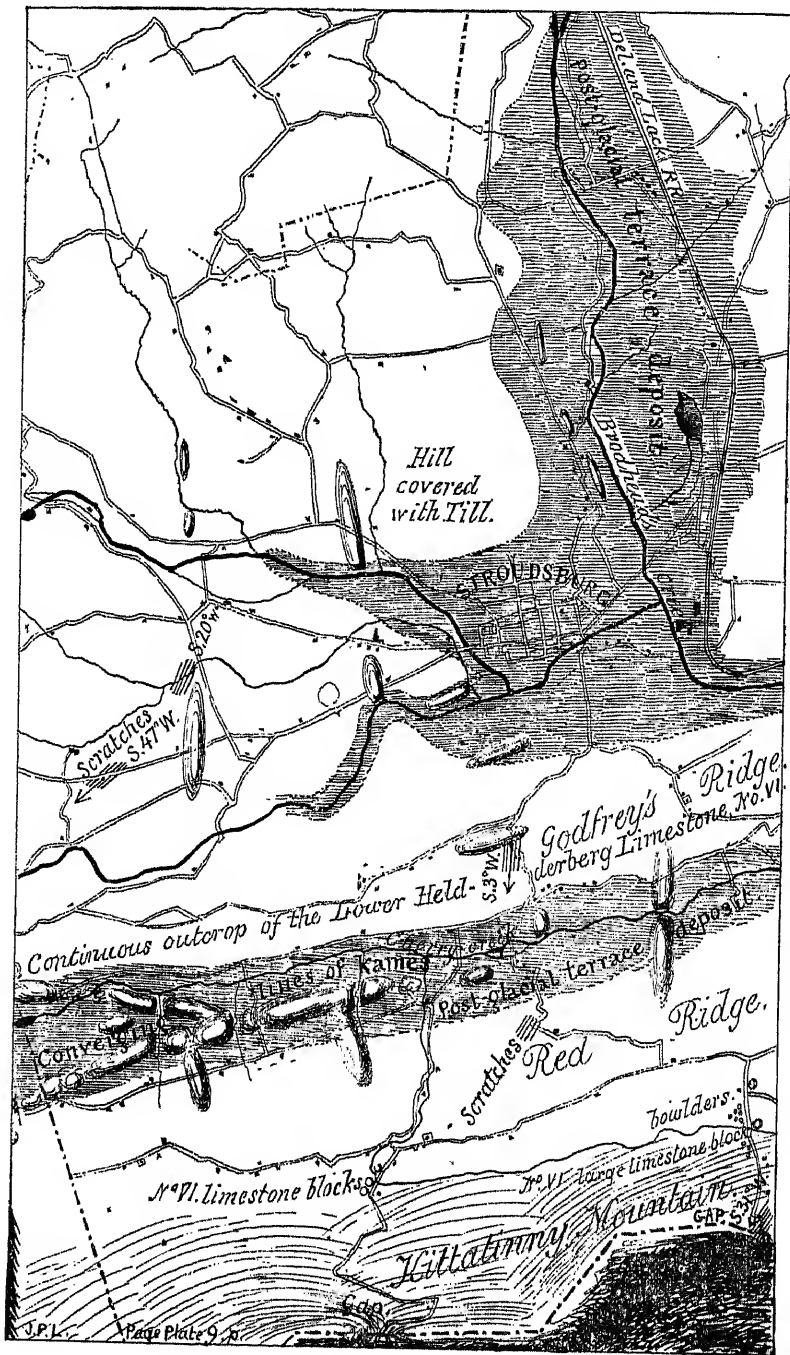
without inlet or outlet like a basin, the most symmetrical of which have been called kettle-hole, sinks, etc. Some of them are filled with water, and numerous lakes thus produced in some places characterize the moraine. These elevations and depressions are similar in shape and in magnitude, as though one was the inverted counterpart of the other; and this is a very distinctive feature.

Professor Chamberlin's description of the Wisconsin kettle moraine, and Professor Cook's of the New Jersey moraine, might be applied to many portions of the Pennsylvania moraine. As will be pointed out in its more detailed description, the moraine in Pennsylvania is often steepest and most sharply defined at the back; and this fact is in accord with what is known of the shape of the terminal moraines at the foot of the local glaciers of Switzerland.

Where less typically developed the moraine is distinguished from the glacial drift, back of it, by the greater size and number of its boulders, the more distant source of such boulders and the more frequent striation of their surfaces.

With the exception of a narrow district which I have called *the fringe*, the line of drift hills which crosses Pennsylvania lies at the precise edge of the drift-covered district. Lying sometimes on an ascending slope, sometimes on a descending one, sometimes crossing a narrow mountain ridge and sometimes forming an embankment across a valley, it rests against no barrier and represents no possible shore line. The absence of stratification, the absence of drift-wood or aqueous fossils, the angularity and striated surfaces of its enclosed stones, together with its topographical position and its peculiar contours, preclude any hypothesis of aqueous origin; while the fact (proved by the striæ) that its course is at right angles to the glacial movement, taken in connection with the remarkable deflections (large and small) in its course, make it a true terminal moraine.

The method employed in *surveying the line* of the moraine was to zigzag along its course from the glaciated to the non-glaciated region and *vice versa*. The point where the moraine crossed each road was marked, and in many cases the moraine was followed continuously for miles.



Each time, a detour was made on each side of the moraine far enough for me to become fully satisfied of the absence of glaciation upon the one side and of its unquestionable presence upon the other. As the moraine is about a mile in width, about 5 miles on each side were generally examined. Sometimes a detour of 40-50 miles was made into the non-glaciated region, to make sure that the region was driftless. Frequently the work was expedited by fixing a point some 50 miles ahead and then filling up the interval.

The general course of the moraine across Pennsylvania is as follows. (See map facing page 1.)

Beginning in Northampton county, a mile below Belvidere,* it appears through the stratified drift as low gravel hills. These, winding up over the slate hills to the west, are soon developed into an accumulation of typical *till*, holding kettle-holes and filled with boulders. Bending in a great curve first westward and then northward it reaches the base of the Kittatinny mountain three miles east of the Wind Gap.

Ascending to the top of the Kittatinny mountain (1600 feet A. T.) the moraine crosses over it, being well shown upon the very summit, and, entering Monroe county, crosses the great valley between the Kittatinny and the Pocono, enclosing in its course several moraine lakes. Having crossed this valley and reached the base of the Pocono escarpment it swings sharply back and around Pocono Knob. Immediately afterwards it ascends the steep face of the mountain to the wide plateau on top, 2100 feet above the sea.

Crossing the center of Kidder township, Carbon county, it reaches the gorge of the Lehigh river about ten miles north of Mauch Chunk, which it crosses at Hickory run. Without swerving from its general north-western course it crosses the Hell-Kitchen mountain, Cunningham valley, and Nescopeck mountain, in Luzerne county, and descends to the valley of the east branch of the Susquehanna river, which it crosses at Beach Haven.

*Latitude 40° 49'.

Here heaps of drift have been washed down the river into terraces.

In Columbia county, after following awhile the base of Lee's mountain it ascends to the summit (1350' A. T.); crosses the high red shale valley, and the crest of Huntingdon mountain; and then descends the north slope of that mountain to the broad undulating valley of Fishing Creek. Taking a northerly course it follows up the *east* bank of Fishing creek to the North or Allegheny mountain.

The summit of the Alleghenies in Sullivan county is covered with glacial striæ and boulders and other marks of glaciation.

In Lycoming county the moraine passes westward along the base of the mountain, crossing Muncy and Loyalsock creeks, and then, near the village of Loyalsock, turns at right angles and ascends to the highlands.

Having reached the summit of the Alleghenies (over 2000 feet above the sea) it crosses the picturesque cañon of Lycoming creek, and passing west through a wild, wooded region nearly as far as Pine creek, it takes a nearly straight north-westward course through the south-west corner of Tioga county and the north-west part of Potter.

On the high ground of Potter county it crosses a great continental water-shed from which the waters flow into the gulf of Mexico, Lake Ontario, and Chesapeake bay. Here the moraine is finely shown at an elevation higher than anywhere else in the United States (2580' A. T.).

The line of the moraine now enters the State of New York in the south-west corner of Allegany county. Running still north-west, and entering Cattaraugus county, it twice crosses the winding course of the Allegheny river, east and west of Olean; then, trending to a point five miles north of Salamanca, in latitude $42^{\circ} 15'$, it suffers a remarkable change of direction.

Turning at right angles to its former course it passes south-west through the south-east corner of Chautauqua county, and keeping approximately parallel to the Allegheny river reenters Pennsylvania in Pine Grove township, Warren county.

It crosses the Conewango river seven miles north of Warren, forming immense accumulations in the valley of the river.

Then, trending west in Warren county (still at a general elevation of nearly 2000 feet above the sea) the moraine crosses one gorge after another, and forms a line separating not only the glaciated from the non-glaciated regions, but also the cultivated from the uncultivated and densely wooded regions.

In Crawford county the line appears in the south-east corner, and crosses Oil creek between four and five miles north-west of Titusville.

In Venango county it skirts the north-west and west boundary of the county, crossing French creek four miles west of Franklin.

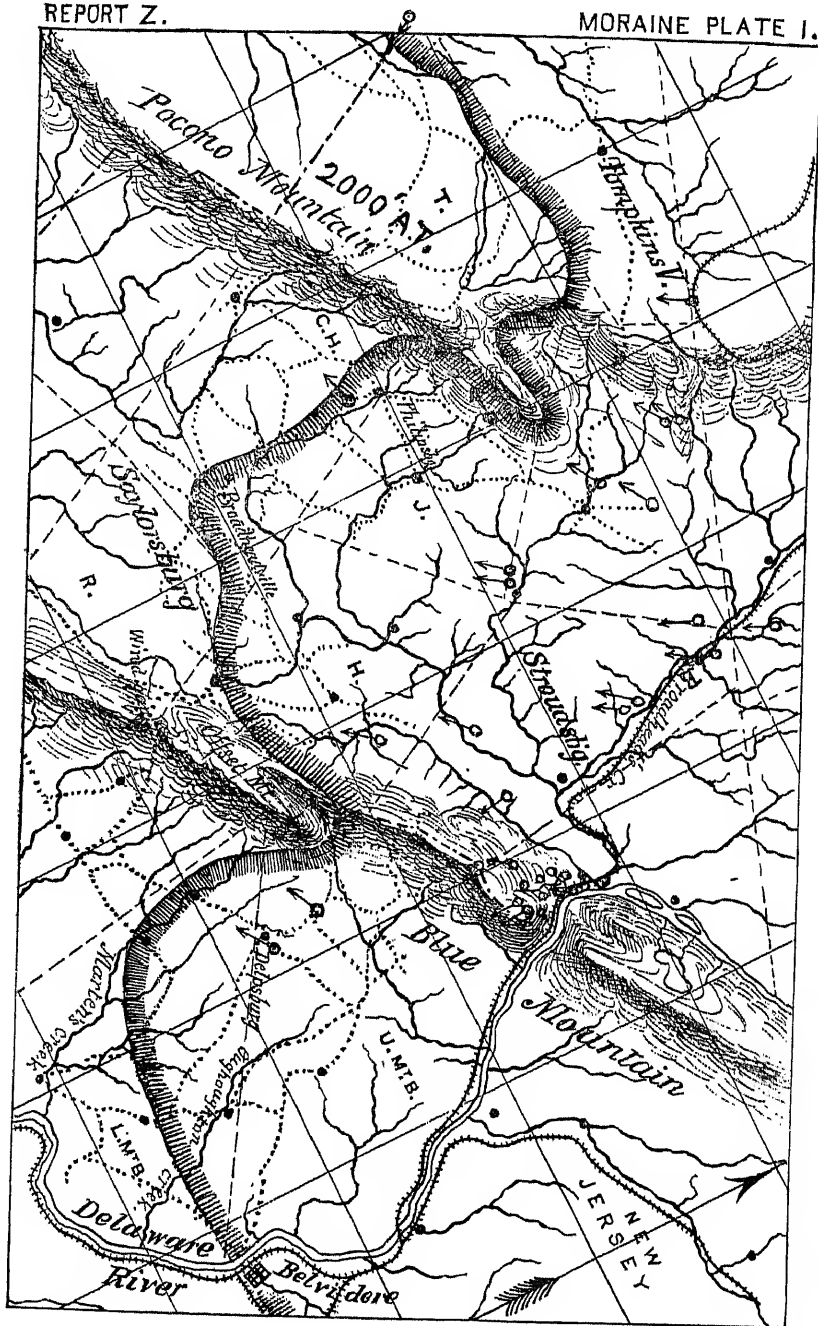
It crosses the three north-west townships of Butler county and the south-east corner of Lawrence, and passes the Beaver river eight miles south of New Castle.

It then traverses the extreme north-west corner of Beaver county, and crosses the Ohio State line in the middle of Darlington township, thirteen miles north of the Ohio river, in latitude $40^{\circ} 50'$.

The moraine thus leaves Pennsylvania at *precisely the latitude* at which it entered the State; and, if a straight line were drawn across the State between these two points, the line of the moraine would form with it a nearly right angled triangle, whose apex was 100 miles distant perpendicularly from its base.

The total length of the moraine is about 400 miles.

It crosses the Delaware at an elevation of 250, the Allegheny at an elevation of 1425, and the Beaver at 800 feet above the sea (225 feet above Lake Erie); but upon the high lands of Potter county it rests on ground nearly 2600' A. T., and its must surface have been about 3000' A. T.



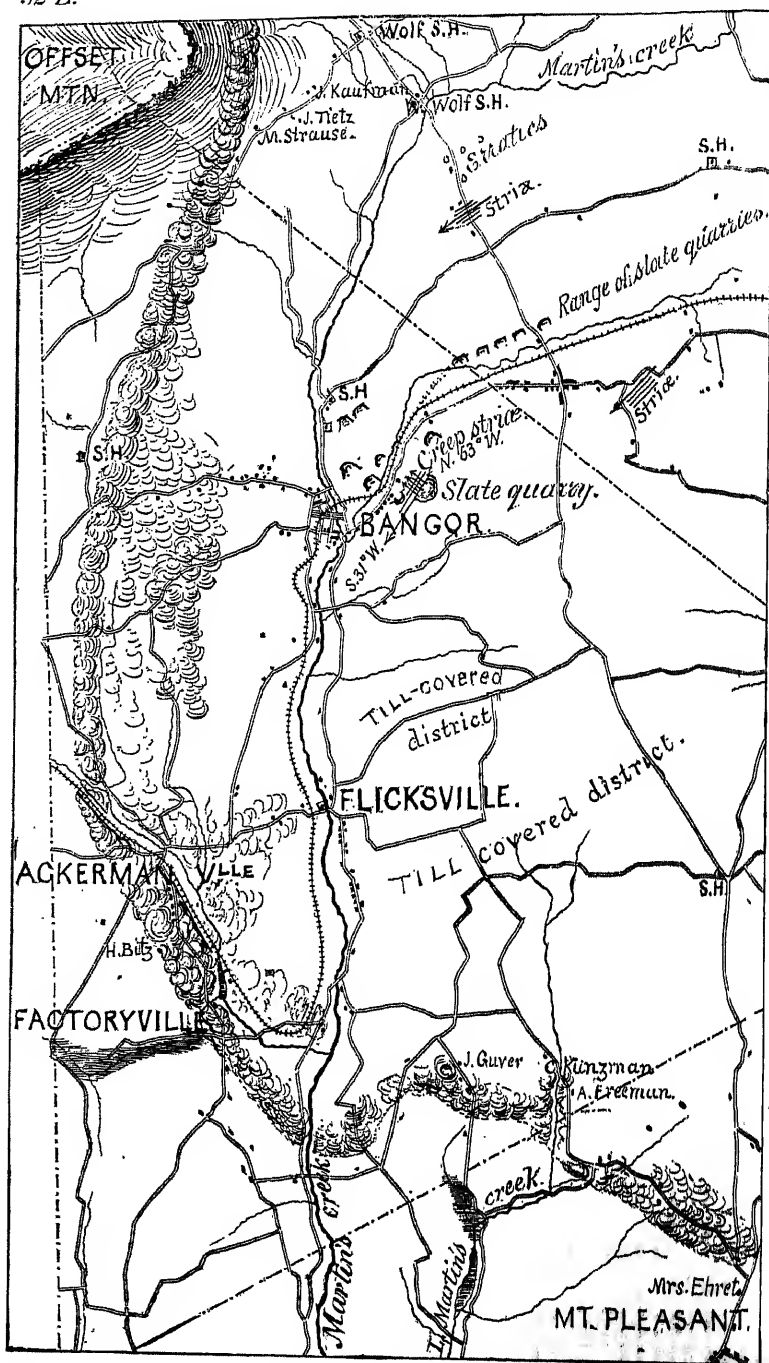
CHAPTER IV.

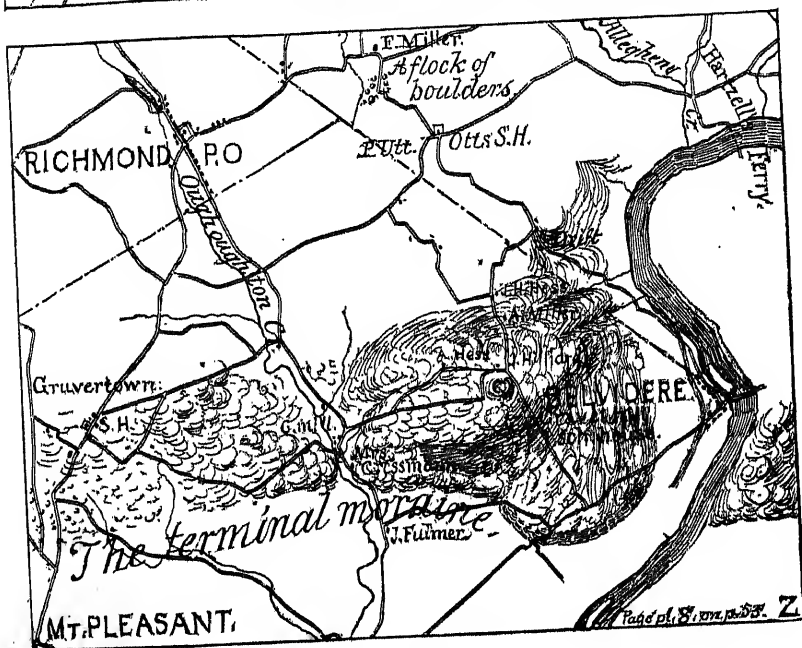
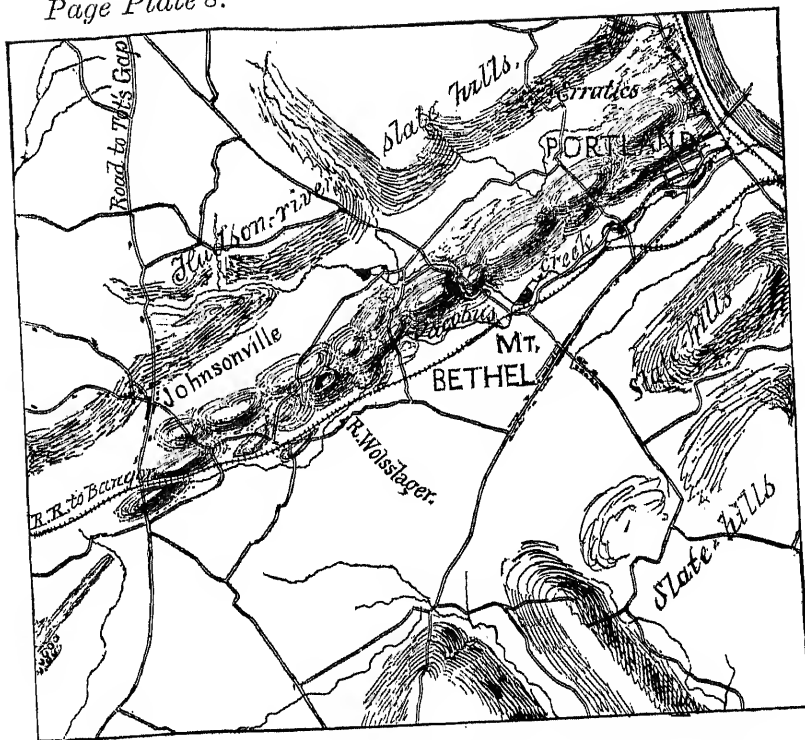
In Northampton County.

At a point upon the Delaware river in Lower Mount Bethel township, Northampton county, less than a mile S. of the bridge crossing to Belvidere, the level terrace of sandy drift which borders the river becomes heaped up into rounded hills and ridges whose longer axes are parallel to the Delaware. These ridges, which are interlocked laterally with one another and which become higher on the more elevated ground farther back from the river, form a line of hills extending in an E. and W. direction. A section of any one of these hills shows it to be composed of a coarse sand and gravel whose pebbles are *water-worn* although quite *unstratified*.

At the immediate river bank there is a good terrace of similar material, about 30 feet high. This line of low drift hills, fully a half a mile in width, is not confined to the valley, but may be traced westward to the tops of the high slate hills bordering the valley. Thus, if one turns northwest from the river road 1 m. S. W. of Belvidere and ascends the road leading toward Richmond, he will cross one drift hill after another and, after passing Gravel Hill school-house, will encounter a true clayey *till* filled with scratched stones.

At about half a mile beyond the school-house, at the fork of roads upon the top of the hill, he will find a district covered with boulders (2 to 3 feet in length) and exhibiting a curious rounded topography. Low rounded hills, connected together irregularly and composed entirely of glacial drift, enclose sometimes a shallow basin-shaped depression or





kettle-hole, such as may be seen at the fork of roads at the house of W. Miller. From this point westward to the Oughoughton creek the till and boulders are continuous and form rounded hills 100 feet or more in height, which but for the absence of all rock outcrops might well be mistaken for hills of erosion, so similar are they to the eroded hills of slate in other parts of the county.

But they differ from the hills in the river valley in being composed of unstratified material. Many of the stones are not water-worn but are sharp; others are rounded longitudinally but rough and jagged on the ends, as though rolled between two hard bodies; and others when closely examined show fine scratches such as might be made by etching with the point of a knife.

Returning now to the river and crossing to Belvidere it will be found that similar phenomena occur also on the New Jersey side of the river. The town of Belvidere lies upon a terrace of *stratified river drift* which both N. and S. of the town, is heaped up into ridges whose axes trend S. W. These extend to a point about a mile S. of the town where they are quite prominent and covered with boulders of a hard gneiss containing epidote and hornblende. The nearest gneissic hills from whence these boulders could have been derived lie at a distance of 4 m. N. E. and E. of this point. Limestone underlies the drift at the river.

It is evident then that the agent which brought these boulders moved in a S. W. direction. The striae both in New Jersey and in Pennsylvania indicate a similar direction.*

Upon a hill immediately north of the town pebbles and fragments of rock occur which show fine striations on one or both sides (Spec. No. 1) and which are not at all water-

*Prof. G. F. Cook in his Annual Report as State Geologist for 1880, p. 36, describes a conical slate hill 2 miles south [south-east?] of Belvidere, 650' high, buried in the moraine to within 90 feet of its top; in which 90 feet the boulders are comparatively few and small; nearly all of them of Medina sandstone, mixed with some of limestone, chert and slate; but none of gneiss; apparently indicating "no movement of the ice from the north-east, or from any point east of that quarter." But this moraine mass may have come from the Kittatinny mountain far to the north-east in New York.

worn ; while, at a mile or more east of the town, bordering a wide plain of stratified drift, rise rounded irregular hills of till and boulders similar to those on the Pennsylvania side, and like them trending back like an artificial embankment across hills and valleys regardless of topography.

That this range of drift hills crossing the Delaware one mile S. of Belvidere represents the southern limit of the great continental glacier and its true Terminal Moraine is, as stated in chapter III, abundantly proved by the evidences of glacial action everywhere north of this line and the absence of all such evidences south of it.

Although more or less stratified in the immediate river valley, it is as already stated composed of true *till* upon reaching an elevation of a hundred feet or so ; and it is evident that the S. W. trend of the water-worn ridges close to the river and the rounding of their pebbles is due to the action of post-glacial floods ; while the more irregular *knob-like character* of the drift hills upon higher ground has been impressed upon them by the glacier itself.

From the Delaware river (water in river 235' A. T.) the accumulation of drift trends westward and, passing over the high hill between the Oughoughton creek and the river, descends to and crosses the creek between the houses of J. Fulmer and Mrs. Cressman not far from a grist-mill. It then ascends the opposite bank and may be seen in a number of places between here and Gruvertown.

Boulders composed of Medina and Oneida sandstone, Clinton red shale, and in fact of most of the geological formations between the Medina (No. IV) and Pocono (No. X) sandstones which outcrop between here and the Pocono Mountain, are represented in the moraine and in the till north of it. Many of them are finely striated. The striations can best be seen when the stone is wet, and it was therefore easier to trace the moraine upon a rainy day.

Just beyond a woods west of the Oughoughton creek a *kettle-hole* may be seen among the rounded masses of drift forming the moraine.

Crossing the road from Mt. Pleasant (Middagh's P. O.) to Richmond, less than a mile north of the former village,

the moraine is represented merely by scattered boulders upon the high ground. Here, as in several other places where high hills lie in front of the moraine, a few scattered boulders lie upon the hills a half mile or so in advance of the main accumulations of the true moraine; but at most places the region in front of the moraine is perfectly free from drift.

Crossing into Washington township about a mile east of Martin's creek it is well shown upon the high hills near the township line north of the house of I. Deats. The house of J. Gruver is upon the moraine, which on the opposite side of the road forms *knob-like hills* enclosing a *kettle-hole*.

The district north of the moraine covered by till and rounded boulders is sharply distinguished from that south of the moraine, where slate is everywhere exposed; sharp fragments of quartz derived from the slate are scattered in the soil, but no till is seen.

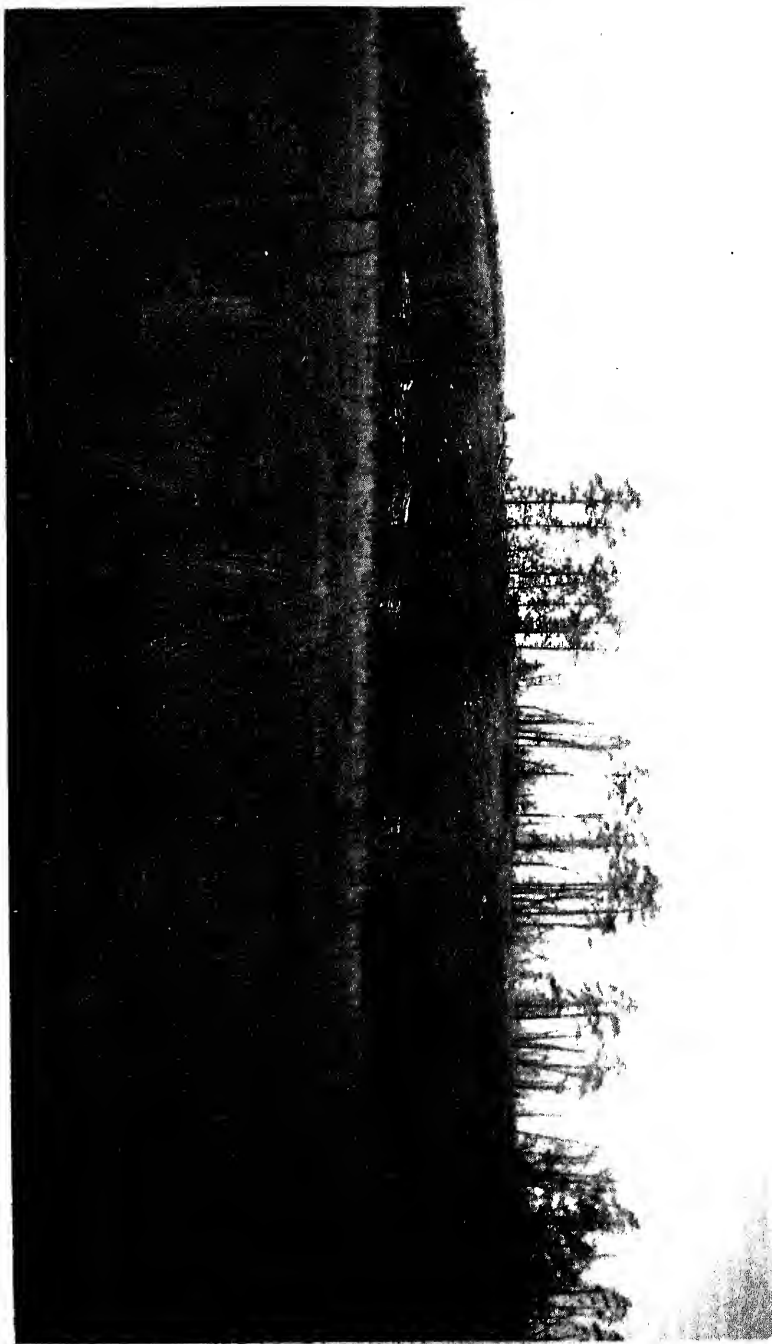
After crossing Martin's creek the moraine turns north-westward and passing through Factoryville is closely followed by the road from that place to Ackermansville, along the W. branch of Martin's creek. The new cuttings for the Portland & Bangor R. R. give *fine exposures* of the moraine between Factoryville (elevation 466 A. T.) and Ackermansville, (elevation 497 A. T.) Such a cut at Factoryville exposes a fine section of till, which is seen to be filled with boulders of all sizes, shapes and material, lying irregularly and without stratification in an impure yellow clayey material. Many of them are striated, and one of Hamilton slate (No. VIII) is eight feet long and weighs many tons.

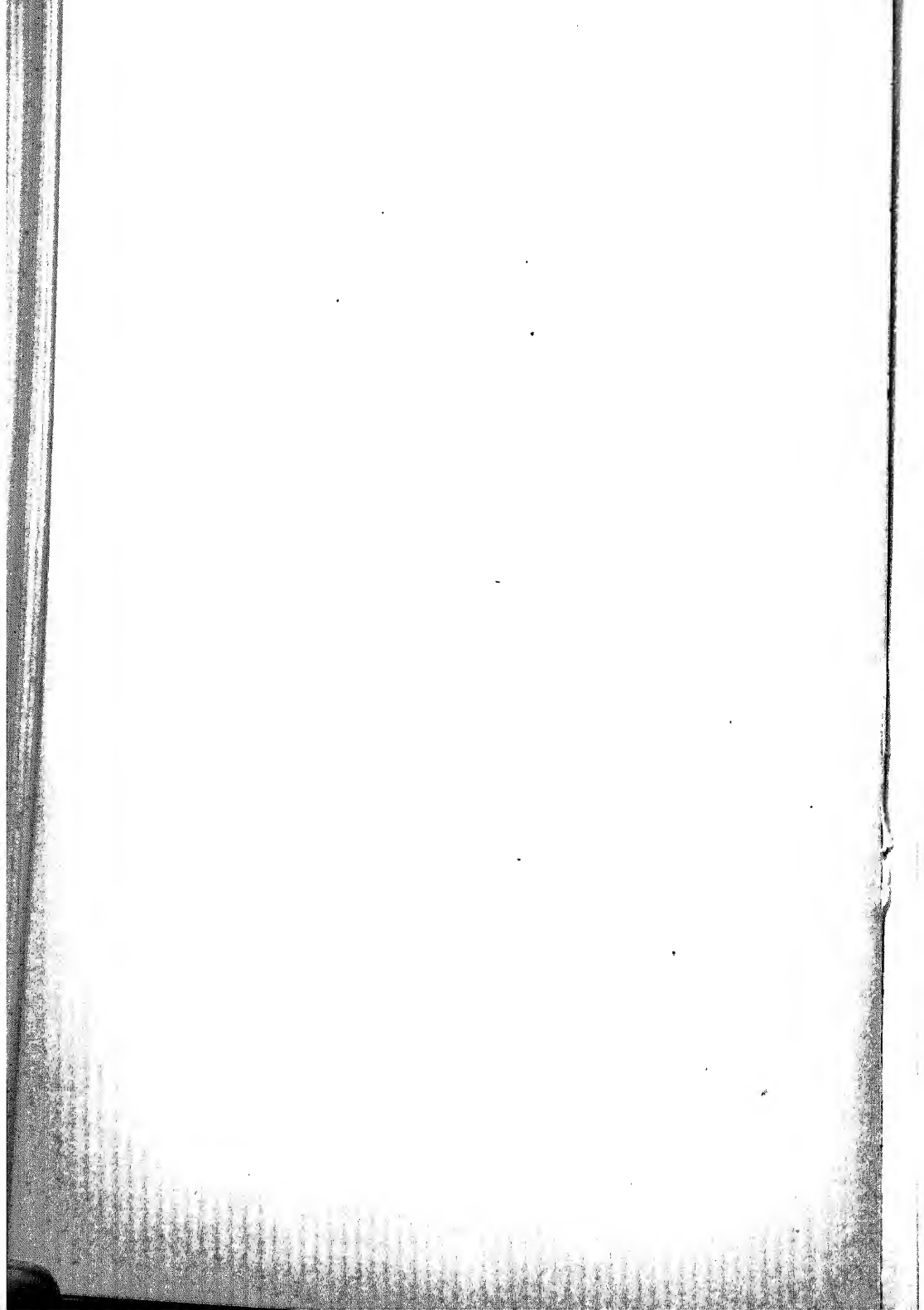
A deep deposit of till of characteristic rounded contours fills the valley of the creek $\frac{1}{2}$ m. below Ackermanville and is cut through by the railroad.

From near Ackermanville the moraine trends northward towards the Kittatinny mountains, bending however so as to keep within the limits of Washington township. The woods north of the village are filled with boulders of the moraine; and upon the roads going northward the character of the moraine can be readily studied.

FRONT SIDE OF TERMINAL MORaine NEAR BANGOR NORTHAMPTON CO. LOOKING SOUTH EAST. (PICTURE REVERSED)

AMERICAN GEOLOGICAL SURVEY





One mile west of Bangor the moraine attains magnificent proportions and is as finely developed as anywhere in the State. It here forms a series of rounded and knob-like drift hills, 100-200 feet in height and nearly a mile in width, which, covered with transported and striated boulders and unstratified *till*, rises abruptly out of the clayey plain to the west and, trending nearly N. and S. exhibits the typical features of a great terminal moraine and is well worthy of study. It encloses many *kettle-holes* which, like those along the southern shore of Massachusetts, have neither inlet nor outlet and often contain accumulations of *peat*.

Trending now somewhat east of north the moraine reaches the northern corner of Washington township and crosses into Upper Mt. Bethel township close to the base of the Kittatinny or Blue Mountain. On the line between the two townships it does not form such high mounds as at Bangor; but they have characteristic contours.

* North of here the moraine enters the forest which covers the side of the mountain.

The moraine having been traced from Belvidere in a continuous line first westward and then northward across rolling hills of *Hudson River slate* it became important to discover whether it ascended the Kittatinny mountain; and if it did, whether it reached the crest of the mountain and descended its northern slope into Monroe county.

It imported much to know whether a great lobe of ice descended from New Jersey along the lower side of the mountain; or whether a tongue projected through the Delaware Water Gap; or whether the glacier close to its southern limit came bodily over the top of the mountain, unchecked by such a barrier, and unchanged in its course.

This last, the most improbable of the three hypotheses, and certainly the least expected by the writer, proved to be the true one; and I am able to show that the moraine crossed the mountain near Offset Knob; that large boulders lie perched all along the summit (1500 feet above the sea) which have been brought from lower elevations several miles to the north; and that, (as shown by the numerous *striæ* on the northern slope of the mountain run-

ning up-hill,) the glacier moved *diagonally* across the mountain uninfluenced in any way by the presence of the Water Gap, and came to an end in the lowlands to the south along the line just described as the terminal moraine.

But as the facts leading to these conclusions are found for the most part in Monroe county the detailed description of them will be reserved until that county is reached.

The region behind the Moraine.

It remains now to point out briefly the various phenomena of glacial action in Northampton county in the region *back of the moraine*.

Where most finely developed the accumulation of *unstratified drift* forming the terminal moraine has a width of about a mile. Back of this special deposit there is a sprinkling of boulders and more or less continuous deposits of *till* of varying thickness which, with the *kames* and other ridges of stratified drift in the valleys, and the *terraces* along the streams, are so characteristic of a glaciated region.

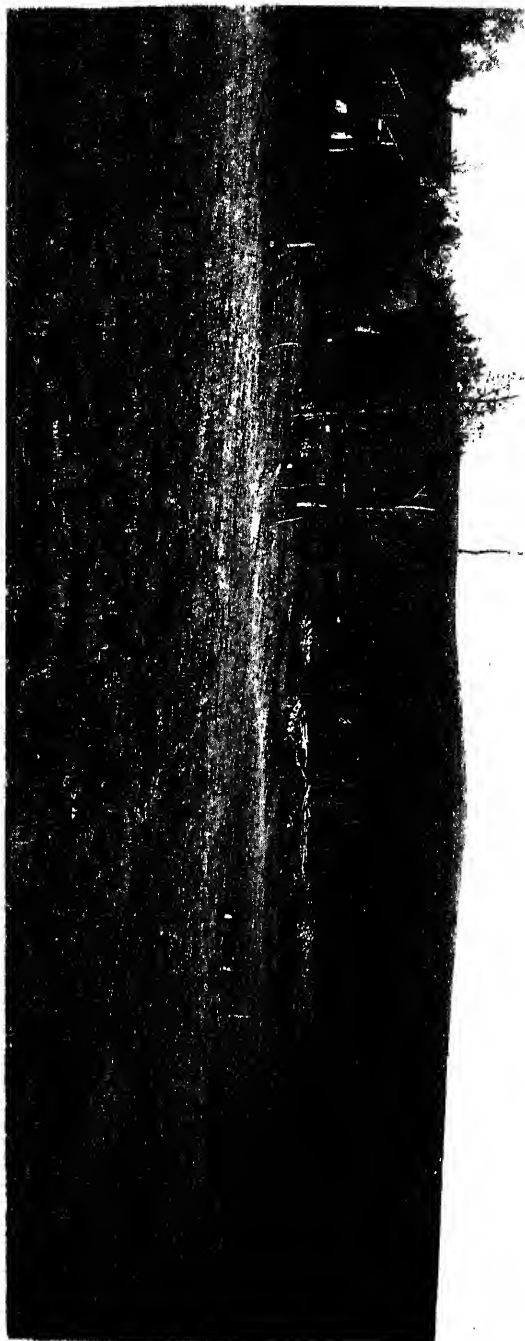
The *till* is by no means evenly distributed. It is scarce and sometimes nearly absent upon the higher hills, and entirely absent upon the summit of the Kittatinny mountain except where the mountain is crossed by the moraine. Transported and striated *boulders* however occur everywhere. The explanation of this fact is that the till was confined to the bottom of the glacier, while boulders were carried on top as well as below; and the ice, whose motion may be compared to that of a viscous fluid, advanced over high hills only by its upper strata, which in melting left *boulders* but not *till*. Numerous facts observed in other portions of the State confirm this explanation.

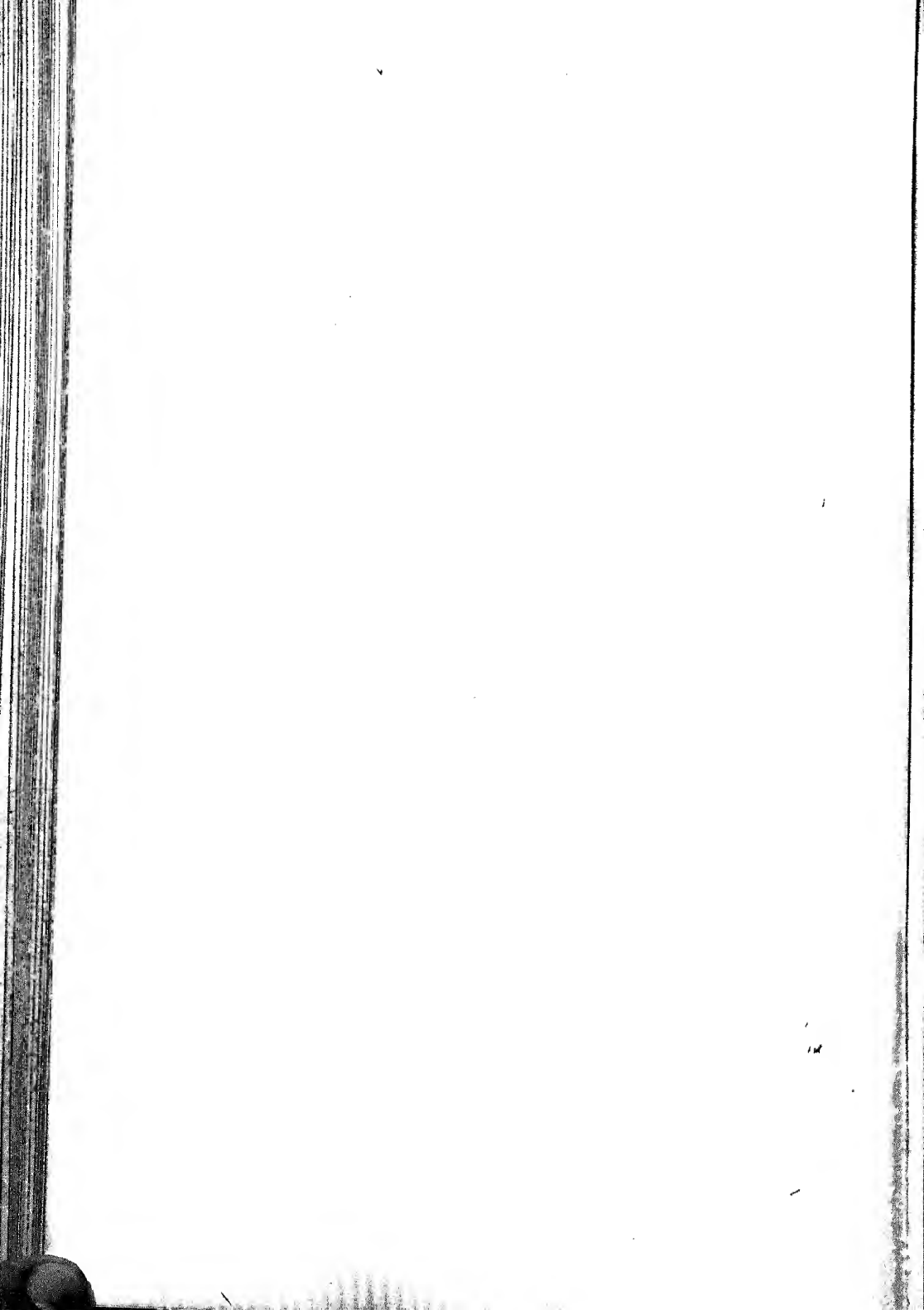
The till is most abundant and often forms deep accumulations and oblong hills at the heads of valleys, and at their junction; and many examples might be given of this fact.

Hills of till of this nature may be seen at several places upon the south branch of Allegheny creek on the road from Hartzel's Ferry to Centreville (Stone-church P. O.). On the road from the latter place to Belvidere a deep deposit of till

INSIDE VIEW OF TERNAL MARIANE NEAR GABOR, NORTHWESTON CO. LOOKING N. W. (PICTURE REVERSED)

PLATE Z. FIGURE 1





has been dumped at the head of a ravine $1\frac{1}{2}$ miles N. W. of Belvidere. It has finely moulded contours, and is cut 50 feet deep by a stream.

The region immediately north of the moraine in Lower Mt. Bethel township is not so deeply covered by till as the region in Upper Mt. Bethel and Washington townships.

The till is deep in the vicinity of Bangor. A fine exposure of typical till filled with boulders at the Bangor slate quarries was photographed by Mr. E. B. Harden, and is shown in Photographic picture Plate IV.

An important ridge of till, several hundred feet high, covered with numerous and large boulders of Medina sandstone occurs in Upper Mt. Bethel township 2 m. N. of Centreville.

This ridge runs across the county in a N. E. direction as if it were a *medial moraine*; and appears to be directly connected with the fine kame about to be described which reaches the Delaware river at Portland.

Boulders in Northampton county.

The *boulders* of the glaciated region are here found to be more numerous in the north and north-east sides of hills than on other slopes. They often occur in "flocks" upon the side of a hill. A flock of them may be seen upon the N. E. slope of a high hill [near the house of F. Miller] 2 miles S. E. of Centreville (Stone-church P. O.) where, many of them, composed of a hard massive dark gray quartz conglomerate, are over 5 feet in length.

Boulders of Medina S. S. derived from the Kittatinny Mt. are most common. Many of these are sharp and, like the frost-broken fragments that are continually forming upon its steep slopes at the present time, were probably lying loose upon the mountain when lifted off and carried away by the ice.

Boulders of other materials are not unusual brought from the mountain region back of the Kittatinny. A specimen of *favosites coral* limestone was found at Bangor.

At the base of the Kittatinny Mountain in Upper Mount Bethel township (near the house of S. G. Labor) a mile and a half west of Slateford, huge sharp boulders of *fossil-*

iferous limestone (Spec. No.) lie upon a ridge in a field close to the mountain. One of these, in great part imbedded in the soil, is 30 feet long and has the appearance of rock in place.

Other similar boulders of large size occur (near the house of T. Broder) a half mile farther east.

All of these have been transported from their home in the valley on the farther side of the mountain, whence they have been raised a thousand feet, carried over the top of the mountain, and after a four miles' ride been dropped in the slate valley of Northampton county.

The most important boulder however is one which the writer discovered in Upper Mt. Bethel township, $2\frac{1}{2}$ miles N. W. of Johnsonville on the road from that place to the Fox Gap. It is a boulder of *labradorite-syenite* $2\frac{1}{2}$ feet long. Since the motion of the ice, as will be shown, was from the north-east, and since no rocks of this character occur south of the Adirondacks and the Laurentian Mountains of Canada, this boulder has been transported from one of these regions more than 200 miles.

Two localities were discovered in Upper Mount Bethel township where the rocks showed *glacial striæ*. On the road from Delpsburg to Portland, $\frac{1}{2}$ m. E. of Delpsburg, nearly opposite the house of J. Johnson, the slate by the road-side is laid bare and rounded into *roches moutonnées*, and bears well-marked glacial striæ, S. 43° W.

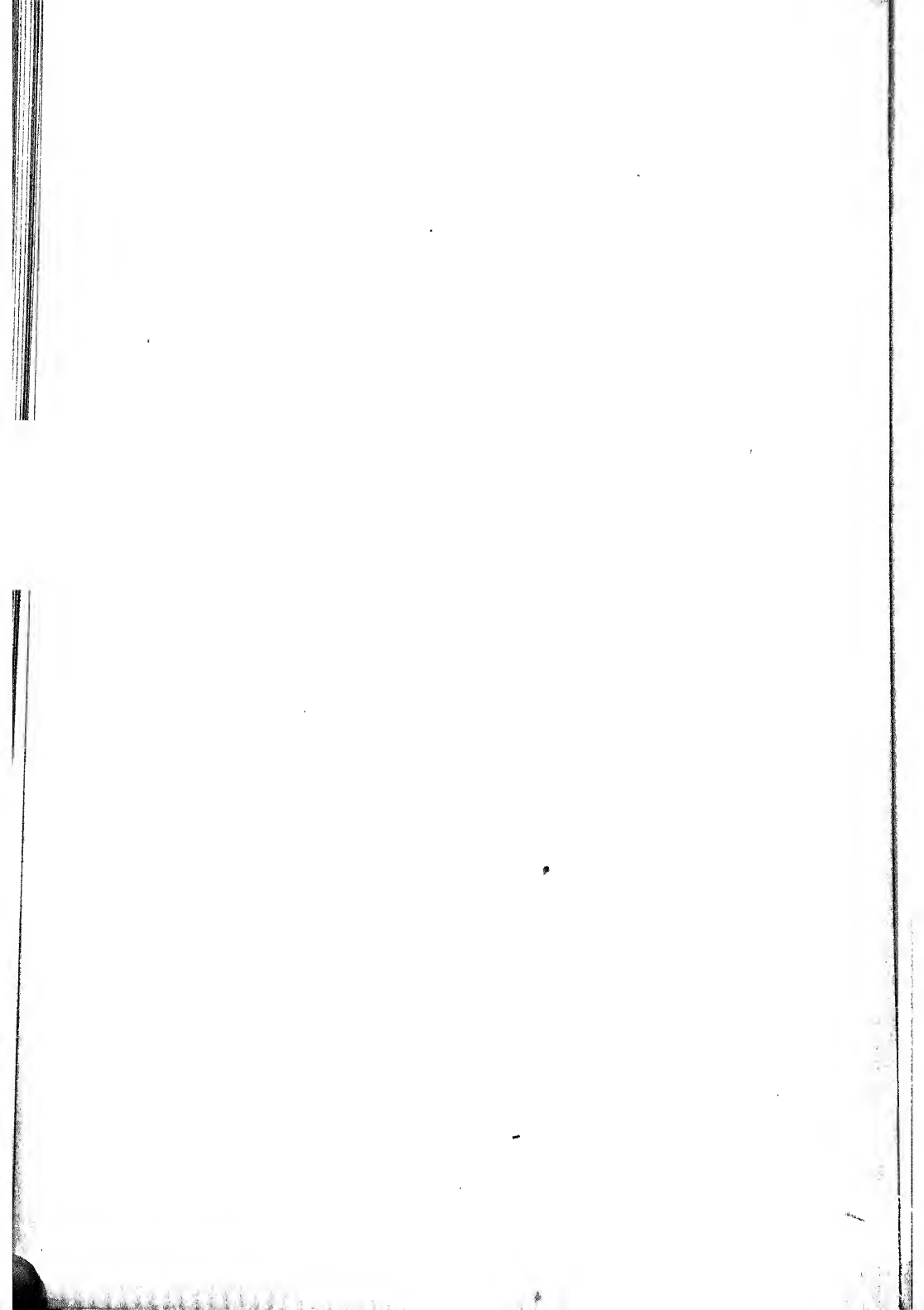
A second locality, upon a high hill one mile north of Delpsburg, on the road between the houses of J. Miller and A. Echert, shows *striæ* (as before upon a rounded surface of slate) which bear S. 58° W. to S. 60° W. These indicate a motion of the bottom of the ice conforming approximately to the trend of the valley and at right angles to the moraine.

Creep scratches.

At the Bangor slate quarries the writer discovered a new kind of striæ, which he has since observed elsewhere, but which do not appear to have been heretofore distinguished by geologists from glacial striæ.



COAL HILLS WEST OF BRIDGE, NORTHWEST CORNER OF SECTION 3, T. 1 N. R. 1 E. S. 1 E.



They may be known as "*creep scratches*." A large body of *till*, 30 feet deep and filled with boulders, rests upon a smooth sloping surface of roofing slate upon the side of a hill sloping north-west. Where a portion of the till has been removed by the workmen the artificially exposed surface of slate shows a number of small narrow scratches which point N. W. or down hill (see Figs. 7, 8; page plate 2; page 32 above.) These fine scratches vary in direction from N. 55° W. to N. 30° W. and have a mean direction of N. 41° W. or about *at right angles to the glacial striæ* of the neighborhood.

It is evident from the slope of the hill and the position of the heavy till resting loosely upon its side that these scratches have been caused by the slipping down hill (or *creep*) of the till under the action of gravity. The action of *creep* upon a hillside is well known in non-glaciated regions, but has not until now been considered a factor in the production of striæ. These are probably post-glacial in age. Closely resembling true glacial striæ, it is important that the two phenomena should be distinguished. It is probable that many striæ which either by crossing other striæ at large angles, or by bearing in unusual directions, have been difficult to explain according to any glacial movement may be to *creep scratches*. Suspicion should always attach to striæ upon a steep slope.

The individual scratches at the slate quarry cross each other at different angles (as is the case with most glacial striæ) the direction varying sometimes as much as 25°. It appears therefore that such direction of striæ does not necessarily indicate any change in the general movement of the striating agent; and it follows that the *mean direction* of a number of scratches observed should always be taken in determining the true direction of striation.

The kames of Northampton.

Of the deposits of *stratified drift* observed in the glaciated region of the country under description by far the most important are the *kames*.

Kames or *eskers* are ridges of stratified material, gener-

ally of anticlinal structure, which mark ancient drainage courses of the glacial waters. They are often many miles in length, and while in general running along valleys, sometimes cross them regardless of local topography. They often form a series of reticulated ridges enclosing kettle-holes or rising into hummocks, and in general show contours very like those of the terminal moraine.

A study of the kames of Pennsylvania has led the writer to regard them as important glacial phenomena, throwing light upon the ancient history of our rivers, and adding largely to our knowledge of glacial times.

Kames are of special importance along the line of the terminal moraine, a position in which they have not before been well studied. Only a few of the most typical can be described in the present report.

Of the kames of Northampton county three are especially instructive.

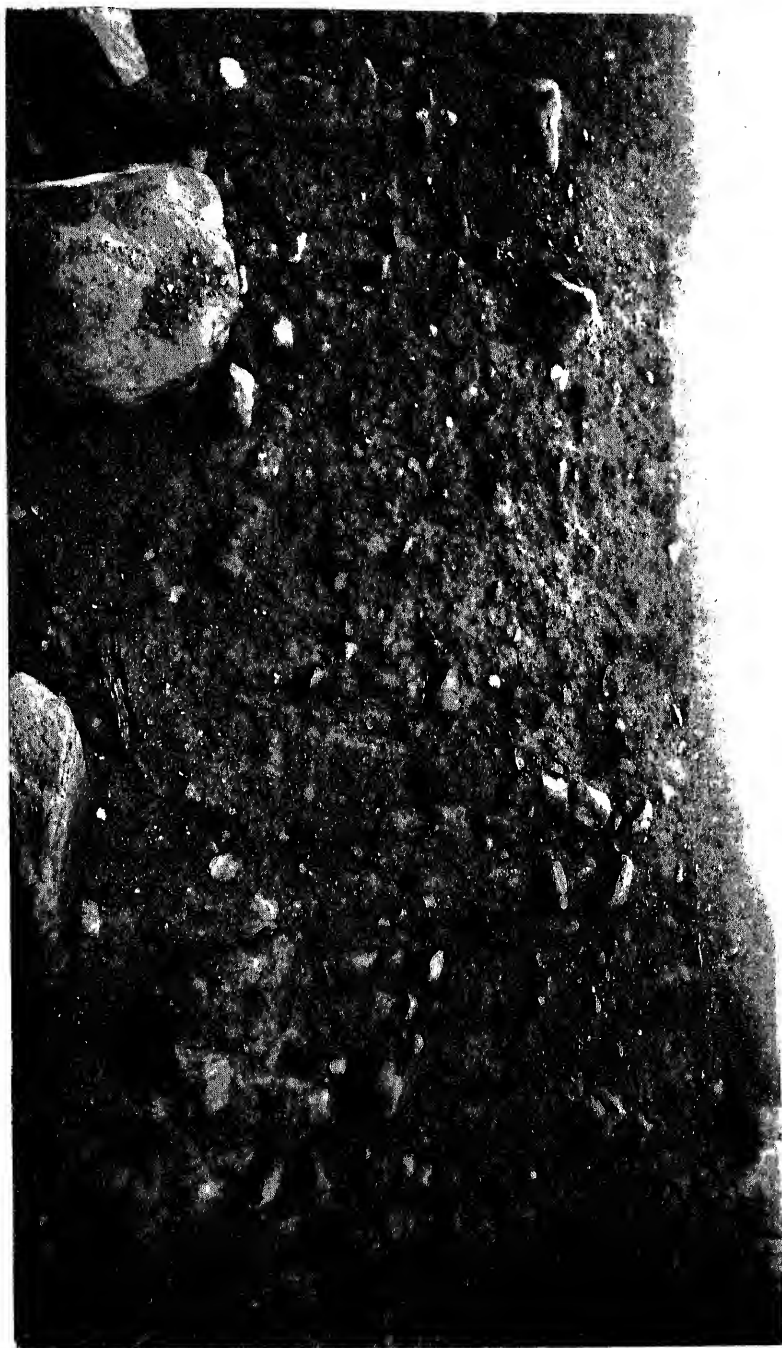
The Portland kame.

The most prominent of these is that which traverses the center of Mount Bethel township in a N. E. direction, follows approximately the valley of Jacobus creek and ends upon the banks of the Delaware at Portland. (See Fig 1, page plate 4, page 38.)

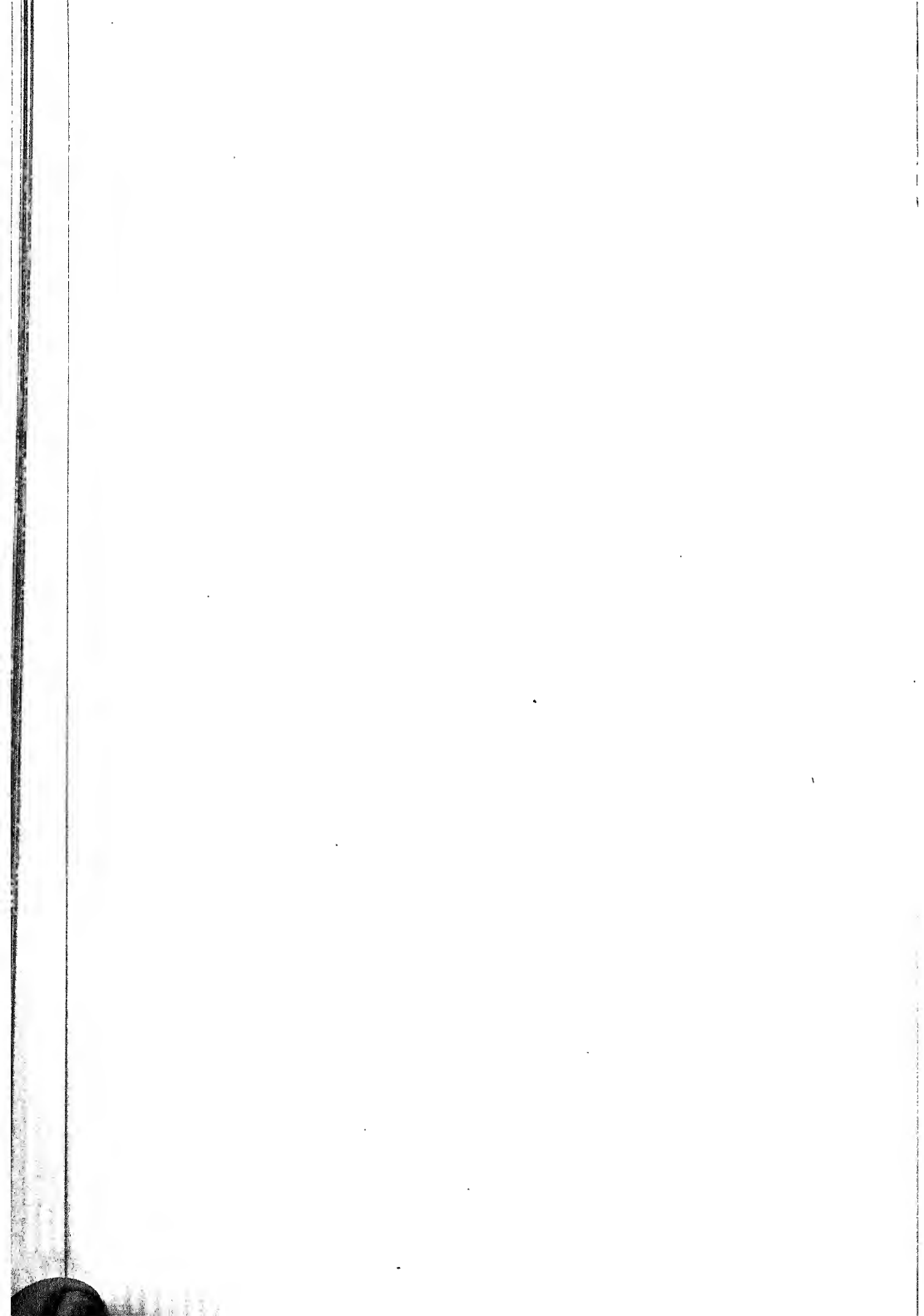
This kame, which has been mistaken for the terminal moraine, is composed of a series of interlacing ridges and hummocks, often enclosing kettle-holes, and formed of stratified sand and water-worn gravel, carrying occasional rounded boulders upon the surface.

The town of Portland is built upon the kame, which here rises 100+ feet above the river forming a prominent hill. Back of the town it can be seen along the N. side of Jacoby creek; and its internal structure is exposed in several places farther S. W. in cuts made by the Portland and Bangor railroad.

Some fine R. R. cuts through several ridges of the kame $2\frac{1}{2}$ m. from Portland show it to consist of a stratified sand overlaid by a boulder-bearing clay, or till, evidence of its having been formed by running water beneath the ice. At this place one mile S. E. of Roxburgh (Johnsonville P.



GLACIAL TILL EXPOSED AT THE BANGOR SLATE QUARRY, AT BANGOR, NORTH-WEST CORNER OF QUARRY REVERSED



O.) the kame is composed of a series of reticulated ridges enclosing typical *kettle-holes*. Four kettle-holes lie close together near the house of R. Wolsslager.

One of these, known locally as the *Devil's Kettle* and supposed by some to be an *old Indian fort*, is a symmetrical oval depression surrounded by a raised rim, 300 feet long by 200 wide, and 30 deep. Like most kettle-holes it has its longer axis parallel to the direction of the kame in which it lies.

In the same neighborhood similar rounded shallow depressions, with neither inlet nor outlet, lie upon the very summit of sandy ridges 100 feet above the level of the surrounding country.

It is evident that kettle-holes are not the result of natural erosion, and that they are in no way allied to ordinary valleys or ravines produced by the action of running water. The instructive fact that a raised rim frequently completely surrounds the kettle-hole so as to elevate it above the surrounding country is conclusive against any theory of ordinary erosion. In fact the *absence of erosion* is one of the most remarkable facts relating to kames and their kettle-holes. The sharpness and steepness of the ridges and the unfilled condition of the *kettle-holes* would present a forcible argument against any great antiquity which might be ascribed to them were it not for the almost unchanged shapes of porous volcanic cones like those of Auvergne.

The kame here described is confined to the valley of Jacobus creek. The high hills on the south are sprinkled with boulders, but hold no deposits of stratified drift.

The length of the kame is 5 miles. Its general elevation near Johnsonville is 600 feet above the sea, or 300 feet above the Delaware river at Portland; giving a north-eastward slope to the kame of nearly 100 feet to the mile. It seems to have been caused by a stream, probably sub-glacial, draining *backwards* into the Delaware river at Portland.

Fox Gap road kame.

Another locality which throws light on the origin of kames is in Upper Mt. Bethel township close to the base of

the Kittatinny mountain and about a mile E. of the moraine.

Here on the road to the Fox Gap a number of small rounded hummocky drift hills, and a series of ridges irregularly interlaced with each other, composed of sandy water-worn drift within, but bearing upon their surface many boulders, form a fine series of small kames.

These kames (well seen between the houses of A. Miller and E. Hess) follow a curved line around Offset Knob.

Close to the flank of the mountain they bear S. 20° W. ; somewhat lower and farther from the mountain they bear S. 30° W. ; still farther down the road they veer yet more S. W. They seem to represent sub-glacial streams which, descending from the melting ice on the mountain, flowed at first southward and then westward around Offset Knob and after issuing from the end of the glacier emptied into the deeply flooded valley of Bushkill creek in Plainfield township.

Immediately north of these kames a great accumulation of till and boulders forms a high ridge upon the side of the mountain. Most of the boulders are of Medina sandstone, but occasional boulders of limestone and of fossiliferous rocks brought from the valley on the other side of the mountain are found. This accumulation at a higher elevation than the series of kames represents the portion of the glacier whose melting supplied the kame streams.

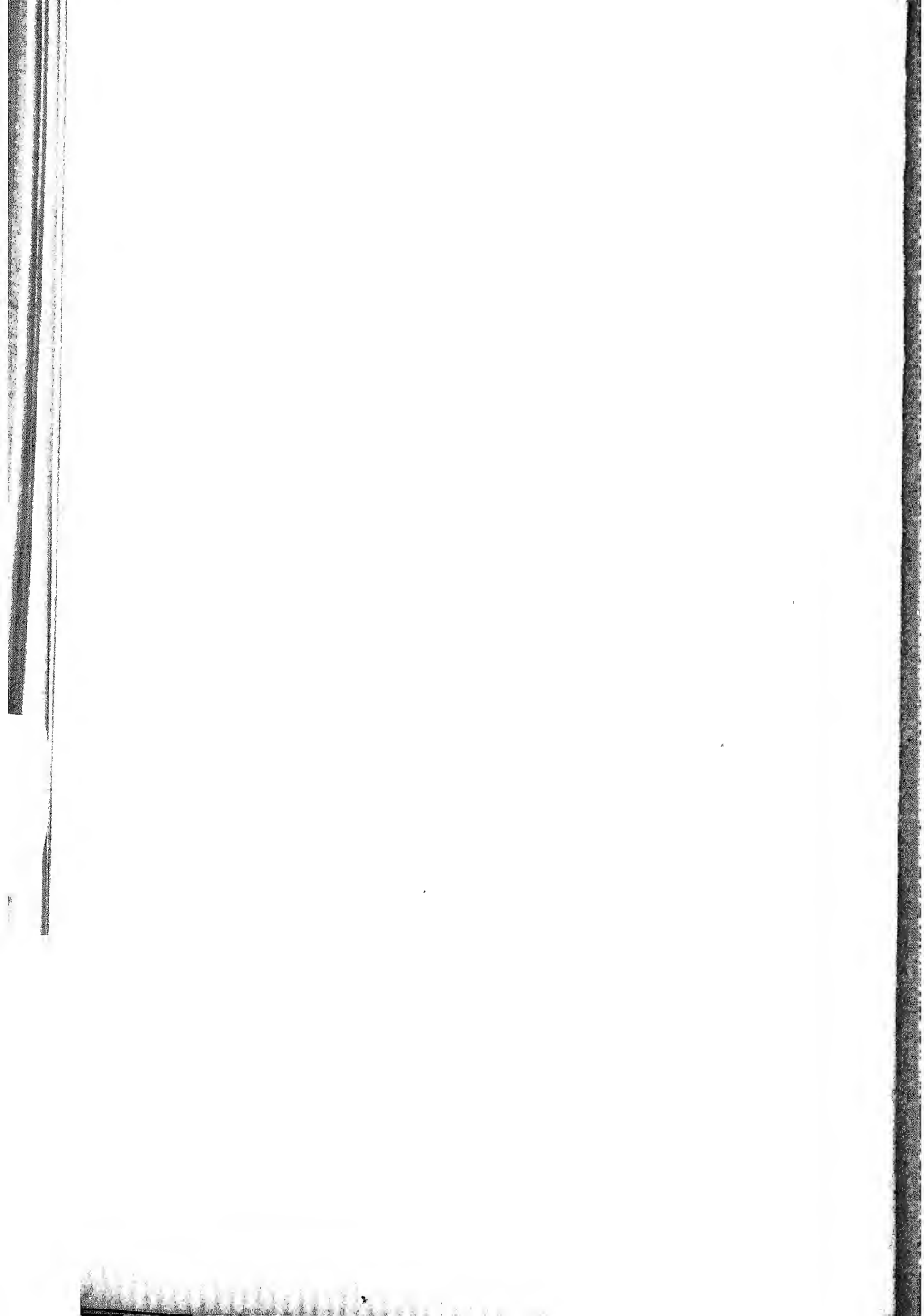
The Ackermanville Kames.

There are two curious little kames immediately south of Ackermanville, in Washington township, which, though but miniature examples, have all the characters of larger kames and offer a suggestion as to their origin.

Two small straight narrow ridges of stratified drift 15 feet high and about 100 feet long may be seen just below the village running nearly at right angles to the valley of the West Branch of Martin's creek. The Methodist church is built upon the west end of one of them. Both of these ridges run from the base of a hill west of the creek toward the stream, their direction being S. 75 E. ; and west of each of them there is an opening in the hill, near the summit of which the moraine lies.

A GLACIATED BOULDER AT THE BANGOR STATE QUARRY, AT BANGOR, IN NORTHAMPTON COUNTY, PA.



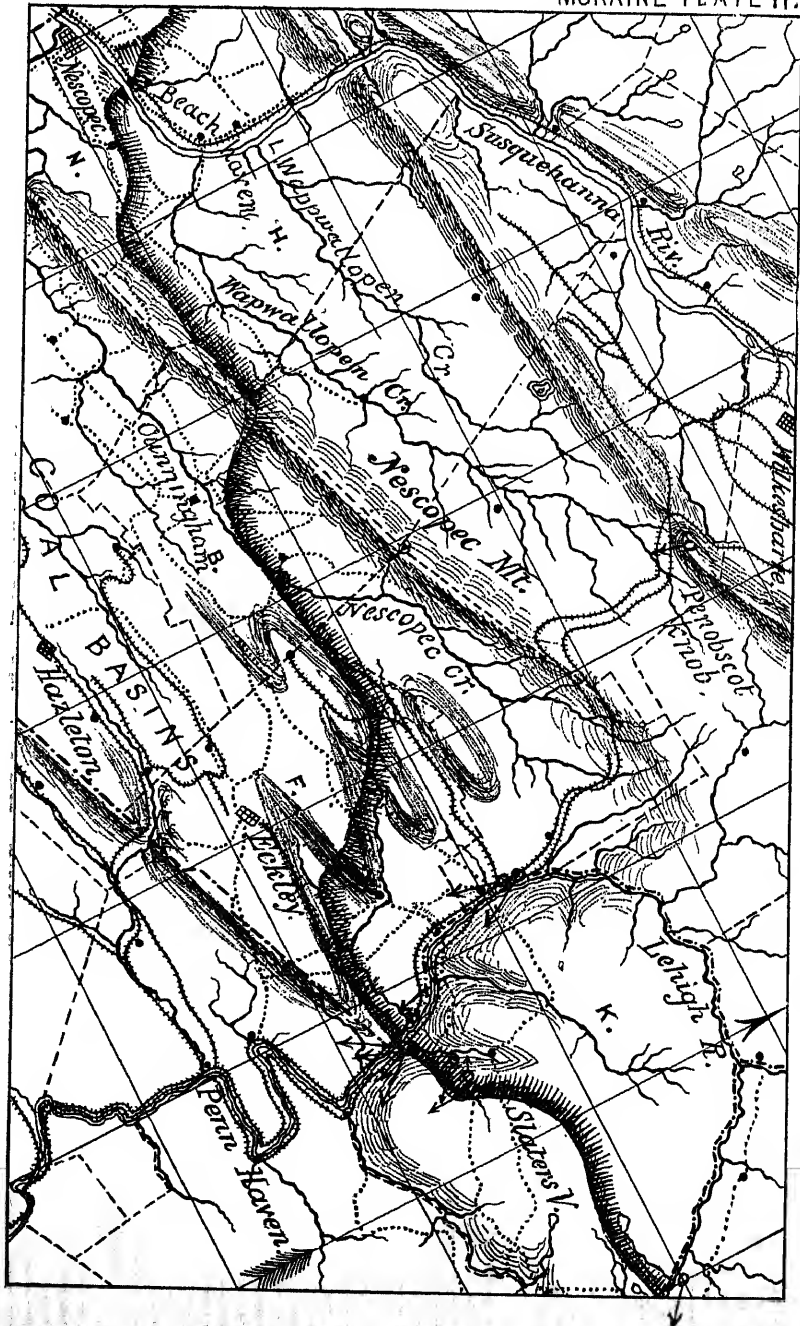


The little sketch map, Fig. 1, page plate 3, page 34, in the scale of 2 inches to the mile, shows their position with reference to the moraine.

Upon examining the structure of these ridges as exposed by transverse cuts made by the R. R. they are found to be composed of stratified sand within and gravel without. The sand shows *flow and plunge stratification* with a distinct *anticlinal* structure. The railroad cut is about 7 feet deep through each of these ridges, each of which has the same anticlinal structure (see Fig. 2, page plate 3.)

These ridges therefore appear to have been deposited by sub-glacial streams which drained the edge of the glacier backwards into the sub-glacial valley now occupied by the West Branch of Martin's Creek. They are here at an elevation of 500 feet above the sea and about 190 feet below the edge of the moraine and are beautiful examples of miniature kames.

Of the numerous deposits of stratified gravels and clays which cover much of that larger portion of Northampton county which lies south of the limit of glacial action the details will be given in a special report.



CHAPTER V.

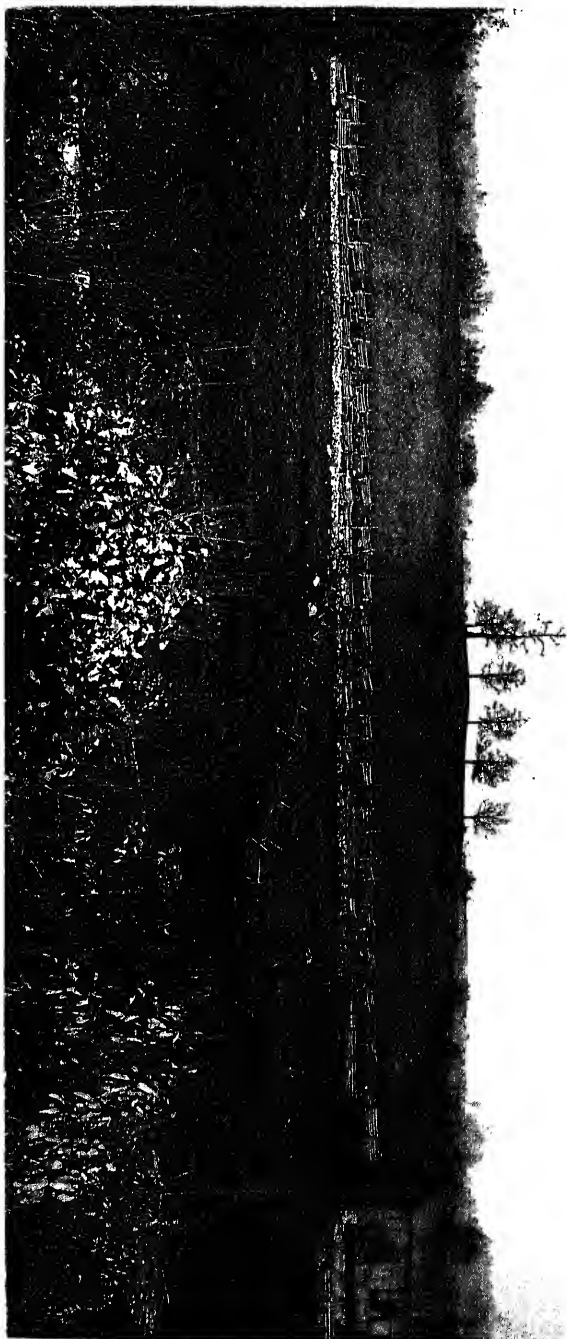
In Monroe County.

The long straight ridge of the Kittatinny Mountain, of which the Delaware Water Gap and the Wind Gap in Monroe county, and the Lehigh Gap in Carbon county are noteworthy breaks, distant from each other about 15 miles, forms the south-eastern boundary of Monroe county.

Between this mountain and the steep escarpment of the Pocono, 12 miles to the N. W. there lies a broad rolling valley, sub-divided by ridges of less elevation into parallel secondary valleys, the most beautiful of which is the well known Cherry Valley.

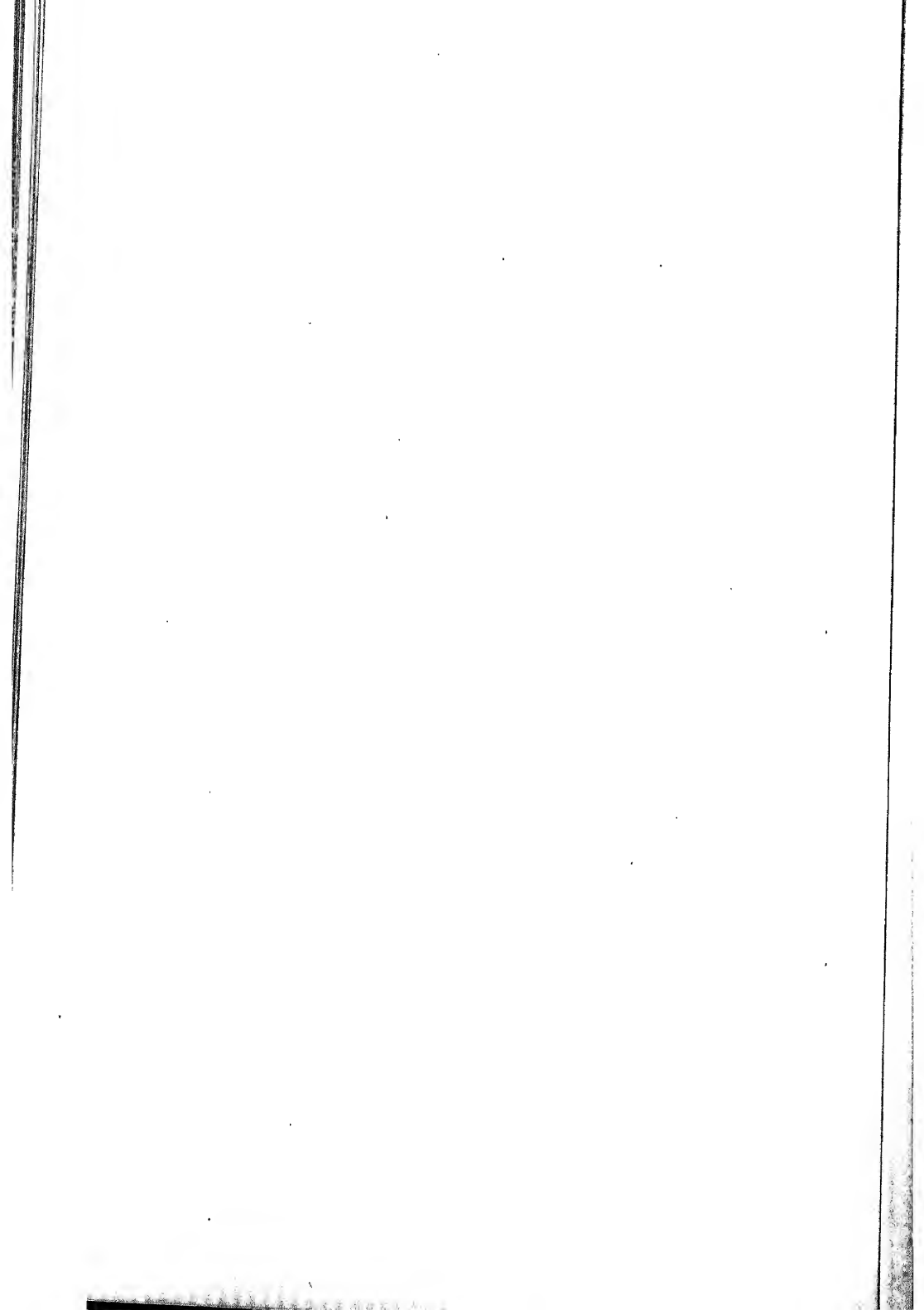
The north-western part of the county is occupied by the nearly level plateau of Pocono Mountain, a wild desolate region 2000 feet above the sea, of which Pocono Knob, 2175 feet high, is a spur-like prolongation beyond the general line of the steep south-eastern escarpment of the mountain. Broadhead's creek, running almost directly southwards, joins McMichael's creek at Stroudsburg and empties into the Delaware a short distance above the Water Gap.

Among the varied geological features of the region are the Medina and Oneida sandstones of the Kittatinny mountain; the Clinton, Marcellus and Hamilton shales of the valley, separated by ridges of upper and lower Helderburg limestones and of Oriskany sandstone; the Catskill red shale and sandstone of the Pocono escarpment; and the great level plate of gray sandstone which caps the Pocono plateau.



TERMINAL MORaine NEAR SAYLORSBURG, MONROE COUNTY, PA.- LOOKING N.N.W. (PICTURE REVERSED)

ARNDT, E. HUBBARD, N. Y.



The glacial geology of this region is probably of as great interest as that of any other portion of the world ; and the course of the great Terminal Moraine winding across mountains and valleys is as complete a proof of the former existence of a continental ice-sheet as can anywhere be found.

A careful examination of the summit of the Kittatinny mountain from the Delaware Water Gap westward to Fox Gap showed that, although covered for the most part with sharp frost-broken fragments of Medina sandstone, occasional rounded boulders of other material were present. In all cases the transported fragments were brought from localities which could be identified in the region to the north. Sometimes these transported rocks are striated. The evidence is decisive that the glacier crossed over the mountain.

West of Fox Gap similar rounded and transported boulders are seen. At a point one and one half m. S. W. of Fox Gap the crest is entirely covered by a deep deposit of *drift* which spreads out so as to form an undulating surface of gentle slopes, sometimes forming ridges or low rounded hills, and enclosing shallow depressions with striated pebbles and boulders brought from the north :—specimens of Clinton red shale from the north side of the mountain ; fossiliferous Oriskany sandstone from the ridge north of Cherry Valley ; upper and lower Helderburg limestones and their enclosed black chert ; Hamilton flags from the region in front of the Pocono ; and other rocks from more distant localities.

A boulder of limestone partly buried in the drift is 5 feet square where exposed ; and a boulder of Oriskany sandstone is still larger by several feet.

The otherwise barren and uncultivated summit is here rendered fertile by the covering of moraine. Fields are cultivated upon the top and on each side of the mountain along the course of the moraine. There is good farming land upon the very summit.

The moraine rises up the southern slope of the mountain, crosses the summit diagonally and then passes obliquely down the northern slope, south-westward, for several miles in Hamilton township before reaching its base.

Immediately west of the moraine, upon the summit of the mountain, a ledge of Medina sandstone forms cliffs, say 70 feet high, which stand up sharp and steep as though untouched by the ice. The moraine is spread out at the foot of these cliffs.

We have here a measure of the erosive power of the glacier, which has eroded about 70 feet of rock from the summit of the mountain from this point north-eastward. Other considerations to be discussed after the description of the course of the moraine in Monroe county indicate that the erosive power of the glacier in Pennsylvania was not greater than this amount.

Descending from the summit of the Kittatinny Mountain in *Hamilton township*, the moraine appears in the valley 1000 feet lower down at Saylorsburg, where it forms a magnificent accumulation, a mile in width, and several hundred feet in depth. A great accumulation of till, covered by boulders (often over six feet in length) and in which glaciated stones abound, fills the valley from side to side. Heaped up into knob-like hills, enclosing shallow kettle-holes, it forms a conspicuous and instructive object.

Lake Poponoming, the most southern *moraine lake* in the State (a sheet of water with no outlet) lies on top of the moraine in a kettle-hole surrounded by hills of drift.

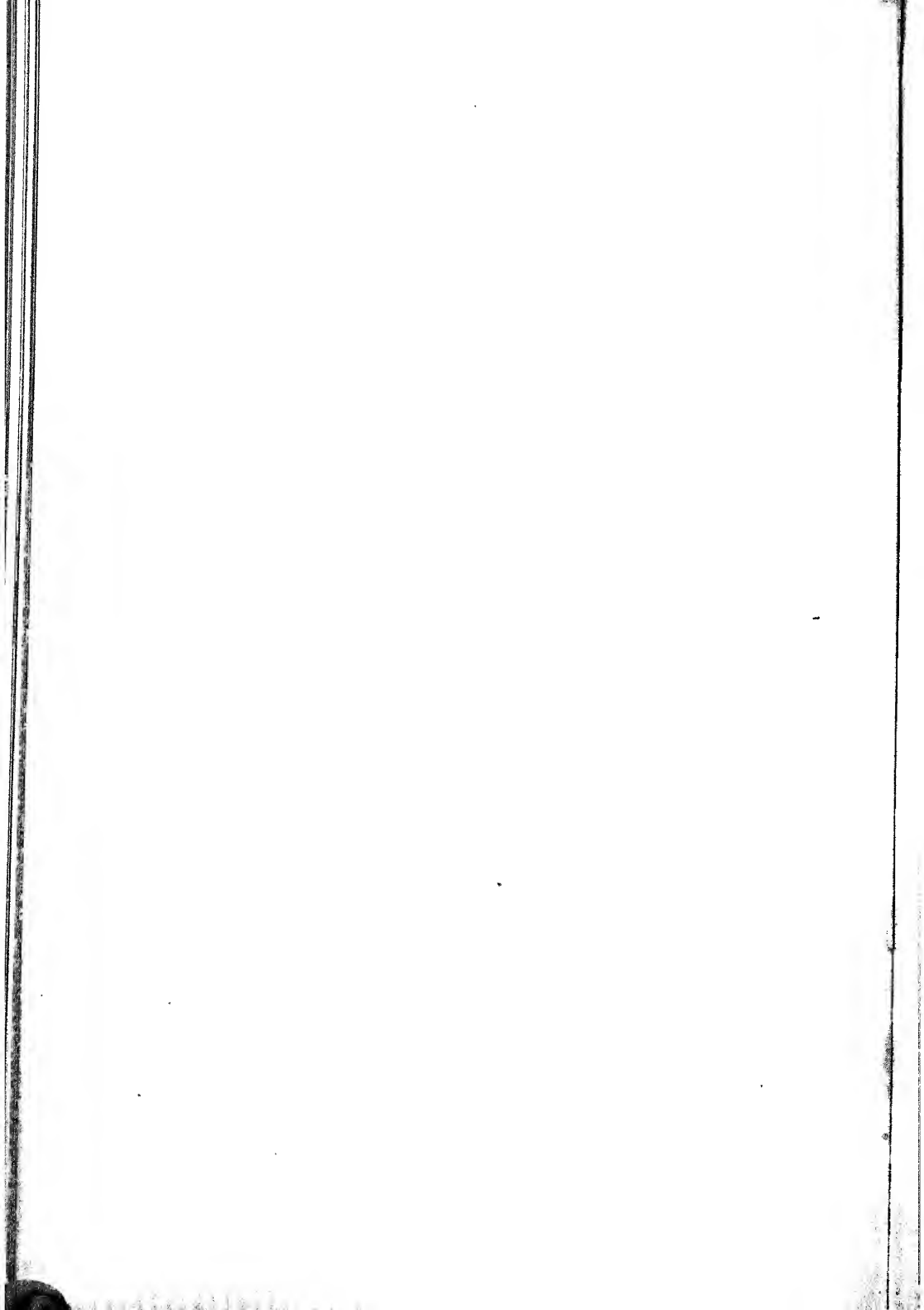
Among the boulders of the great moraine at Saylorsburg was one of *gneiss*, over a foot in diameter, found near the Lake House. The nearest point from which this boulder could have been transported is the Adirondack region of New York, 250 miles distant.

The moraine here forms a water-shed between streams flowing into the Delaware and those flowing into the Lehigh. A fine series of kames leading from the moraine backward down Cherry Valley, and on the other hand a deposit of boulder-bearing clay and stratified gravel leading westward from the moraine to the Lehigh near the Lehigh Gap, indicate that streams of water from the edge of the glacier flowed in both directions, one of them being sub-glacial. The facts will be given in detail after a description of the line of the moraine.

KETTLE HOLES IN THE MORaine IN CHERRY VALLEY, MONROE COUNTY, PA. - LOOKING N.E. (PICTURE FEVERSED.)

AMERICAN PHOTOGRAPHIC CO. N. Y.





Entering *Ross township* the moraine trends northward close to the eastern line of the township keeping generally W. of the road from Saylorsburg to Brodheadsville. It ends sharply a short distance west of Lake Poponoming, near the house of S. Altimus, west of which house not a single boulder or other sign of glacial action was found upon the hills of shale. In the north-eastern corner of Ross township the extreme edge of the moraine rests upon slaty hills, and consists merely of large scattered boulders of Pocono SS. and other rocks, with but little till, and none of the characteristic rounded drift hills which occur farther back from its edge. In several places where hills rise immediately in front of the moraine a narrow *fringe of boulders* appears slightly in advance of the moraine accumulations, and the front edge of the moraine at some places is not quite so sharply defined as its back portions.

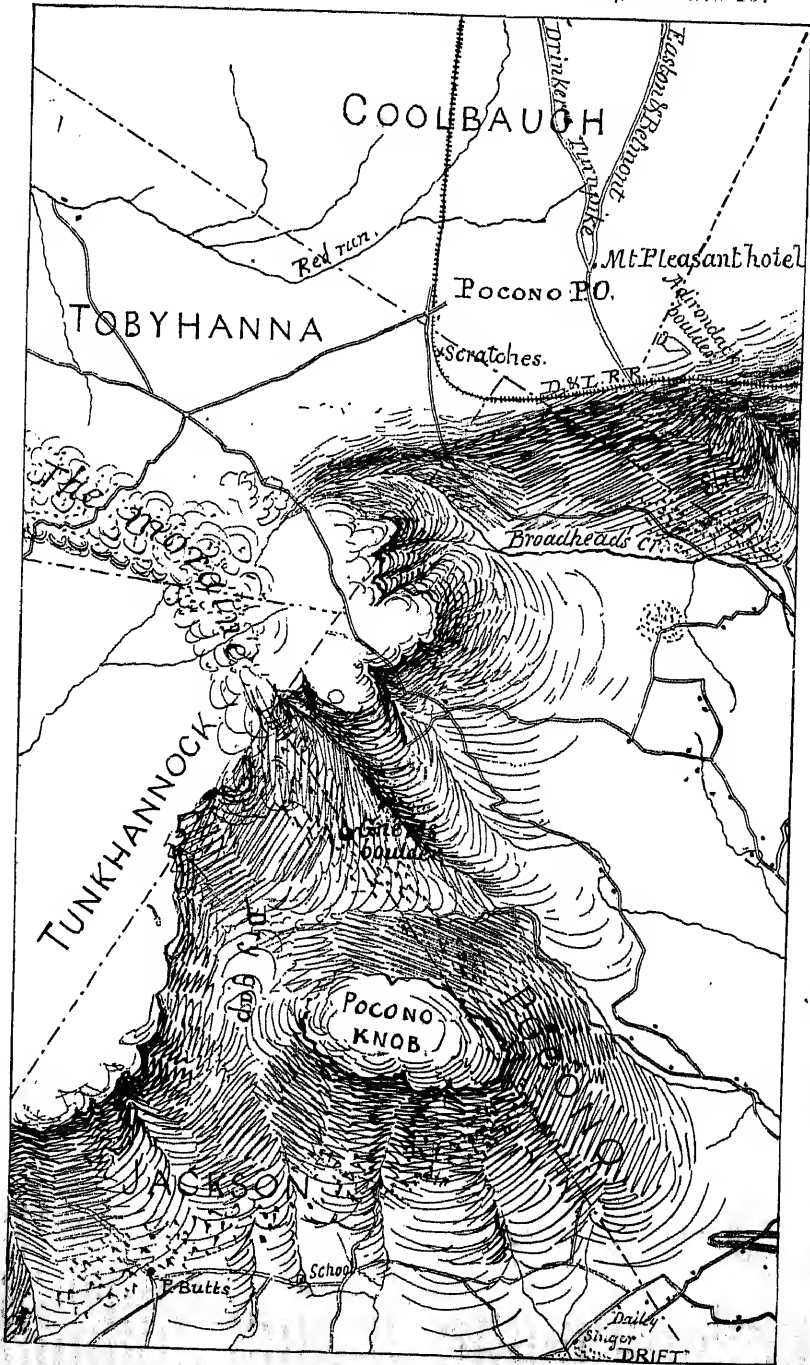
In *Chestnut Hill township* on the other hand the line of the moraine as it rests against the high slate hill known as Wire mountain can be traced with exactness. No drift whatever occurs upon Wire mountain in front of the moraine; and no boulders are found until reaching the precise edge of the moraine, which, is readily recognized by till, boulders and a series of low rounded drift hills.

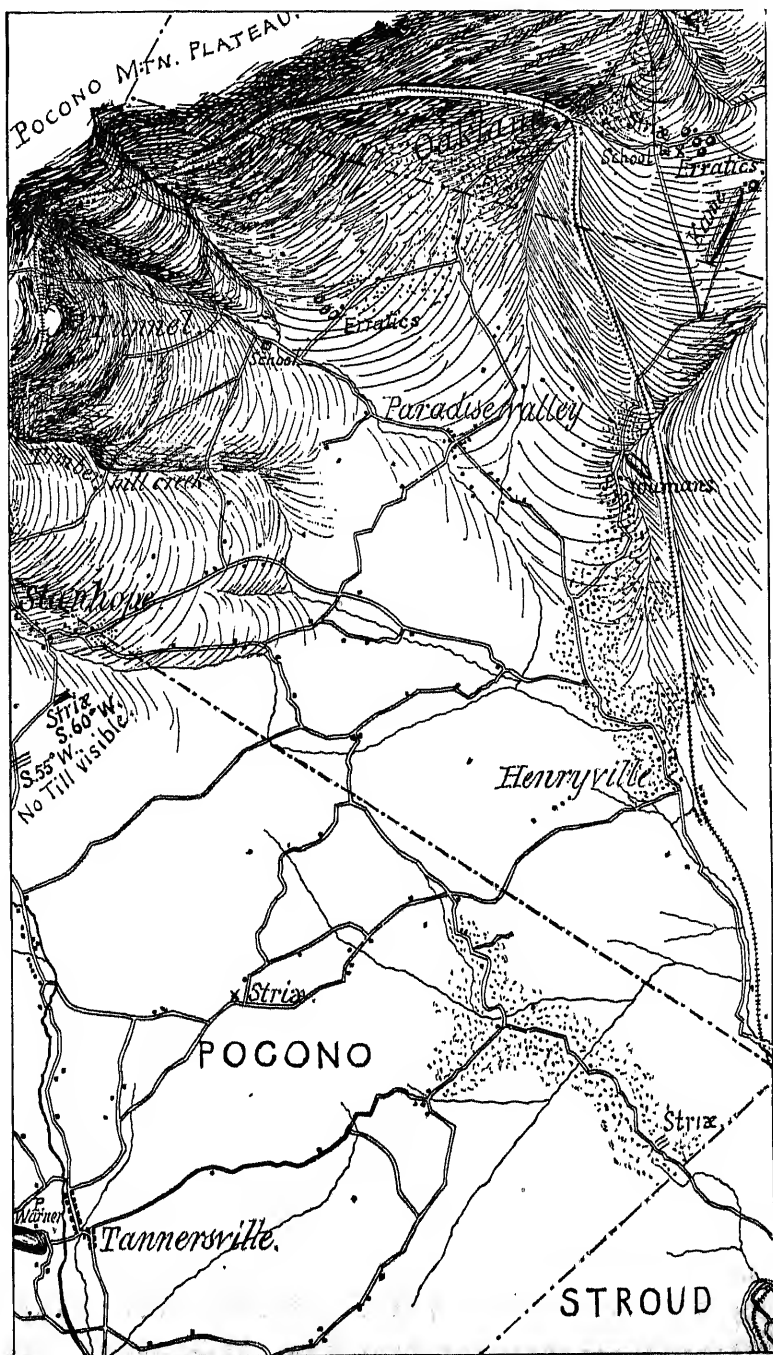
After a short westward course along the north base of Wire mountain the moraine turns northward, passes through Brodheadsville and pursues a nearly straight northward course to the base of the Pocono escarpment.

A deposit of yellow clay and stratified gravel appears in front of the moraine at Brodheadsville, and tells of an ancient drainage-channel leading from the glacier to the Lehigh along the valley of Hokopoko creek; while here also, back of the moraine, the presence of fine kames leading north-eastward along the valley of McMichael's creek indicates a sub-glacial drainage in an opposite direction.

The moraine here and as far north as the Pocono mountain rests on or near the water-shed between the Lehigh and the Delaware rivers.

Lake Minneola has neither inlet nor outlet and lies in the midst of a series of typical knob-like moraine hills. Close





to it is a large *kettle-hole* which is dry. Scratched stones are abundant in the ridges and hummocks which surround these kettle-holes.

North-west of Brodheads ville the moraine is finely shown along the western side of McMichael's creek.

Rounded hills of till, over 100 feet in height and filled with scratched stones, continue up the valley of the creek and are occasionally washed into terrace plains of *stratified drift*.

The moraine rises upon the hills to the west of McMichael's creek, so as to pass about a mile west of McMichael's P. O. (Phillipsburg).

Upon the side of *Pocono Mt.* north and north-west of McMichael's P. O. the moraine shows finely as a series of ridges, knobs and kettle-holes, which, filled with boulders and with scratched pebbles, and often 100 feet in height, forms a typical accumulation of drift rising upon the side of the mountain to a height probably of about 1450 A. T.

On the road from McMichael's P. O. to *Long Lake*, where the moraine suddenly comes to an end can be distinctly seen at about $1\frac{1}{2}$ miles N. W. of the village. Beyond this point no drift whatever occurs either upon the side of the mountain or upon the plateau at the summit until the road again meets the moraine north of Long Lake.

The *Pocono plateau* is covered by a sandy soil made by the decomposition of the underlying Pocono sandstone. It contains numerous fragments (both sharp and weather-worn) of the sandstone, but not a single transported boulder or sign of glaciation. Nor was any evidence of glaciation observed upon the summit of Pocono Knob. Sharp fragments of frost broken rocks cover the highest portion of the ridge, which (2175 feet above the sea, as measured by barometer) appears to have projected wedge-like into the glacier, uncovered by the surrounding ice.

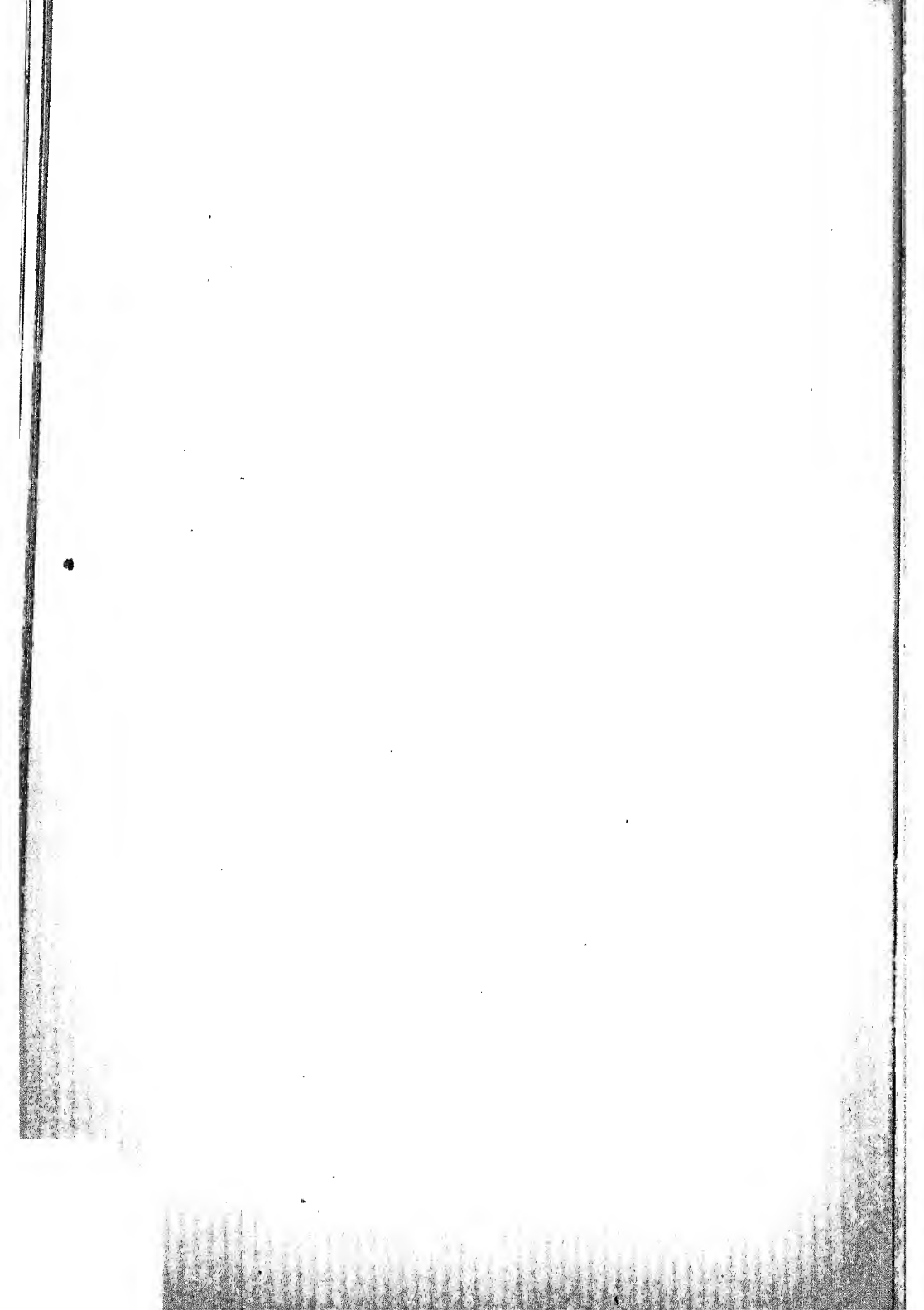
In *Jackson Township*, therefore, since great moraine-like accumulations of drift occur on both the north and the south sides of Pocono Knob, but not on its summit, the line of the moraine appears to wind closely around it.

There is a fine series of drift ridges high up on the south-

THE TERMINAL MORaine CROSSING CHERRY VALLEY MONROE COUNTY, PA. LOOKING S. W. (PICTURE NOT REVERSED.)

A. WOODRUFF, ESQ. PHOTOGRAPHER.





ern slope of the mountain, at an elevation of 1600 A. T., immediately south of the "Dry Gap."

Pocono Knob, west of Tannersville, is a very steep cone about 1000 feet high. Accumulations of drift a half mile in width and extending high up against the rocky cliffs probably represent the moraine as it winds around the end of the mountain. On the northern slope of the knob the moraine is heaped up into ridges and conical hills, which, though covered with dense woods and traversed with difficulty even on foot, has been traced continuously along a line of very great interest. (See Note at end of volume.)

The moraine ascends the slope of the mountain on the north side of Pocono Knob and is finely shown in drift hills, moulded into characteristic knobs and ridges, covered with boulders. A boulder of gneiss 2 feet long lies near the boundary of Pocono and Jackson townships about 3 m. N. W. of Tannerville at an elevation of 1620 A. T. A similar boulder (Spec. No. —) at an elevation of 1810 A. T. was found a short distance beyond. The moraine is here 2 m. W. of Pocono Knob, which must therefore have stood up like a narrow peninsula nearly surrounded by the sea of ice.

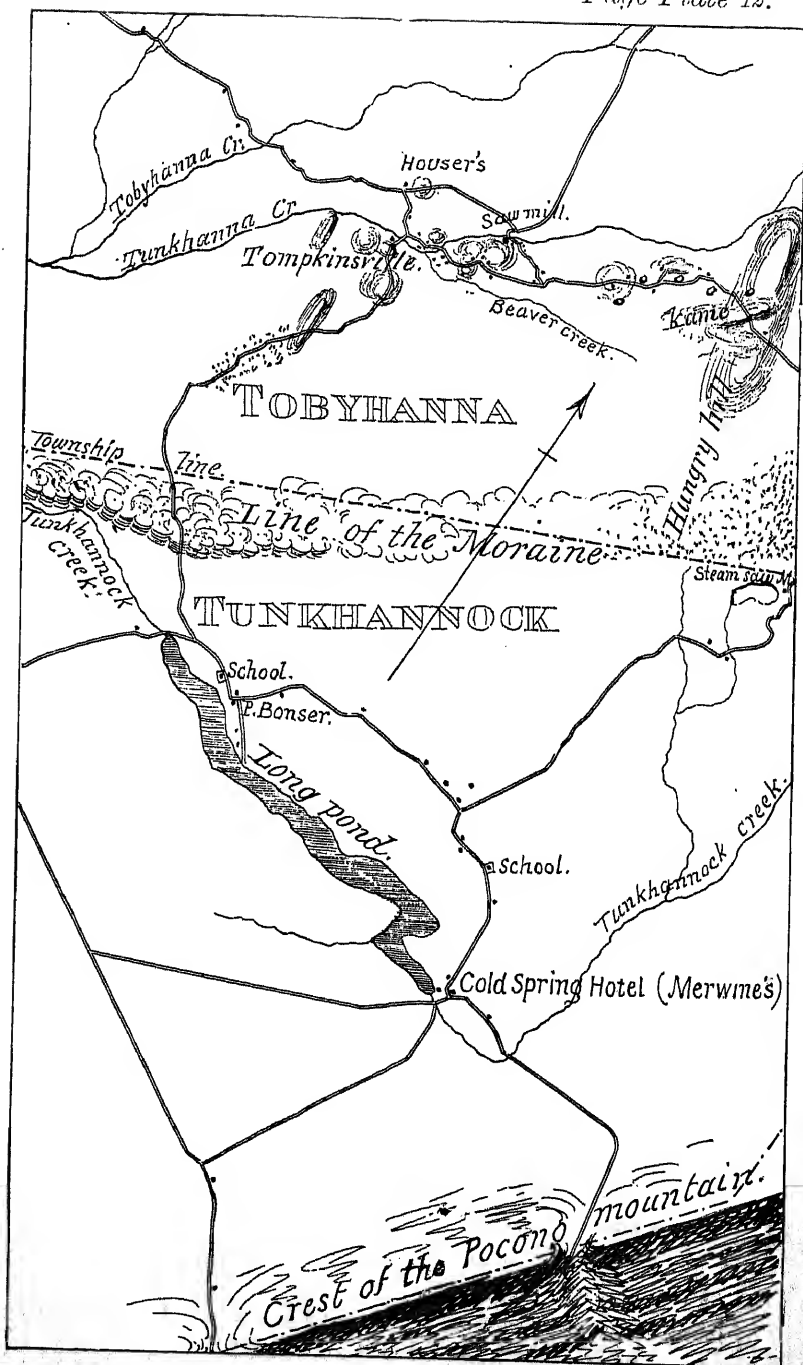
The moraine finally ascends to the very summit of the mountain, where, near the boundary of Jackson and Tunkhannock townships, at an elevation of 2020 feet above the sea, it is heaped up into typical moraine hills of drift and encloses a *moraine lake* without inlet or outlet and of undetermined depth.

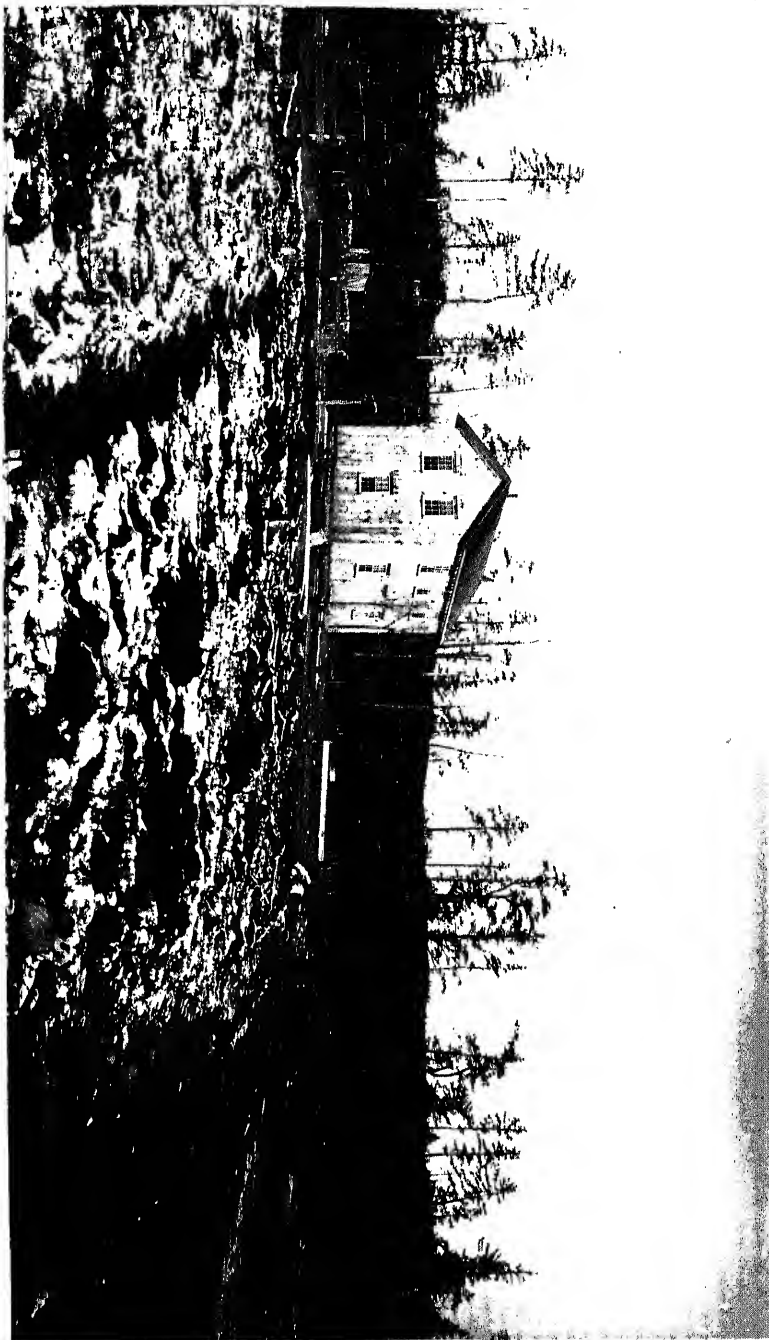
Deep Lake lies in an amphitheatre of drift hills at the edge of the great mountain plateau. It is a kettle-hole some 20 rods in diameter, surrounded by a rim of glaciated material thrown up into knobs and ridges, which rise from 50 to 100 feet above the level of the water.

Scratched pebbles (Spec. No. —), transported boulders and occasional gneissic pebbles occur, and the till is so deep as to conceal all rock outcrops.

Long Ridge is the local name of one of the most remarkable parts of the moraine where it enters *Tunkhannock township*.

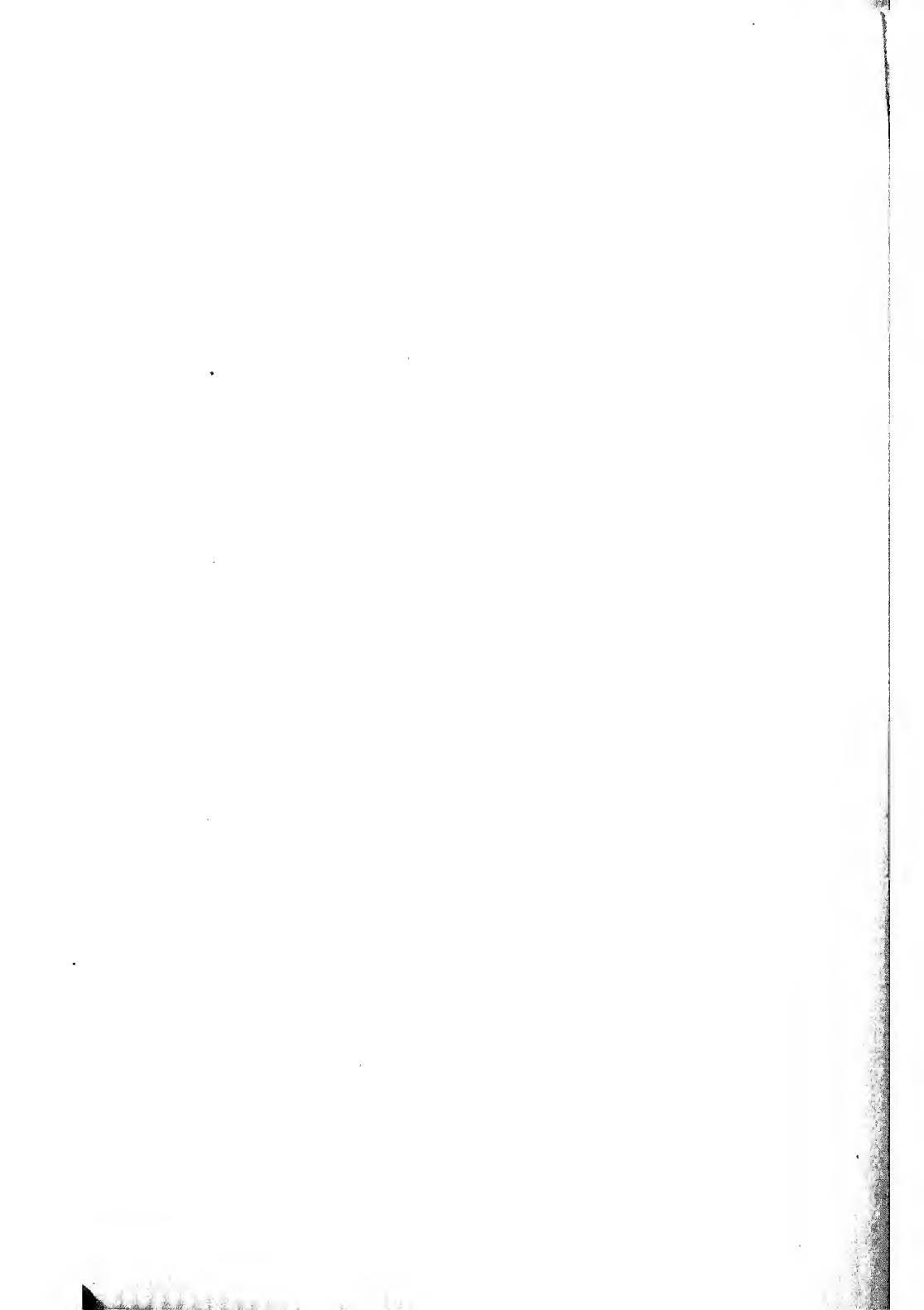
Suddenly rising out of the level sandy plain of the





LONG RIDGE: THE TERMINAL MORaine ON THE POCAND PLATEAU, 2000' A.T. YONKOE CO.
LOOKING N. N. E., (PICTURE REVERSED.)

PAINTING, N. N. E. CO. "A"



Pocono plateau (2000 to 2100 feet above the sea) this great ridge of moraine hills 12 miles long, over half a mile wide, and one hundred feet or more in height, a vast accumulation of transported boulders of all kinds, sweeps in a majestic half circle around the eastern and northern boundary of Tunkhannock township.

Lying as it does in a region accessible for the most part only on foot, it was only after several weeks' exploration, and after a thorough search throughout the whole northern portion of Monroe county, that the true line of the moraine was discovered.

Trending first northward and then westward it is finely shown on the line of Tobyhanna and Tunkhannock townships near the north-eastern corner of the latter.

From Heller's saw-mill northward are heaped an accumulation of knobs and ridges a mile wide (2150 feet above the sea), with kettle-holes and moraine lakes, covered by huge boulders, both sharp and rounded, often striated and sometimes made of gneiss.

Deer Lake is another kettle-hole in the moraine.

Further west the moraine passes $\frac{1}{2}$ m. north of *Long Pond* a lake apparently caused by the blocking up of its northern outlet by drift. Long Pond lies at an elevation of about 1920 A. T. in a depression in the plateau in front of the moraine. This whole plateau region in front of the moraine is characterized by a shallow sandy soil, upon which grows a scanty vegetation of scrub pine and oak, producing scenery like that of southern New Jersey. No signs of glaciation appear until the line of the moraine is reached north of Long Pond. One quarter mile N. of the pond boulders of Catskill sandstone and of other material begin to appear, and become more and more numerous farther north. Half a mile further, rounded hills of true *till*, completely covered by boulders, and of characteristic contours, reveal the typical moraine. As in many other places, the moraine hills are most largely developed and most sharply defined at the *back* portion of the moraine rather than at its extreme front edge.

The moraine, trending now somewhat south of west, crosses

the turnpike 2 m. S. E. of Soxville on Tunkhannock creek, and enters Kidder township, Carbon county, a little more than one mile S. of the line of Tobyhanna township. Where crossed by the pike the moraine forms distinct hills on the N. side of Tunkhannock creek covered by scratched pebbles and transported boulders (Spec. No. —.) Many of these are of Catskill sandstone. Others are of Pottsville conglomerate, Pocono sandstone, Carboniferous shales, etc. The elevation is here about 1850' A. T.

It is here to be observed that the ground immediately in front of the moraine is not so high as the moraine by say 40 feet, a fact showing that although the course of the moraine is plainly influenced by elevations of great extent, local changes in topography have no effect upon it. The moraine lies upon southward as well as up on northward slopes and, as here shown on a grand scale, is as finely developed on a mountain top as in a valley.

As in the course of exploration the moraine was crossed and re-crossed upon the mountain, each time a sandy plateau devoid of all signs of glaciation was found in front, while back of the moraine were deposits of till and boulders, kames of stratified drift, and glacial striæ upon exposed rock surfaces.

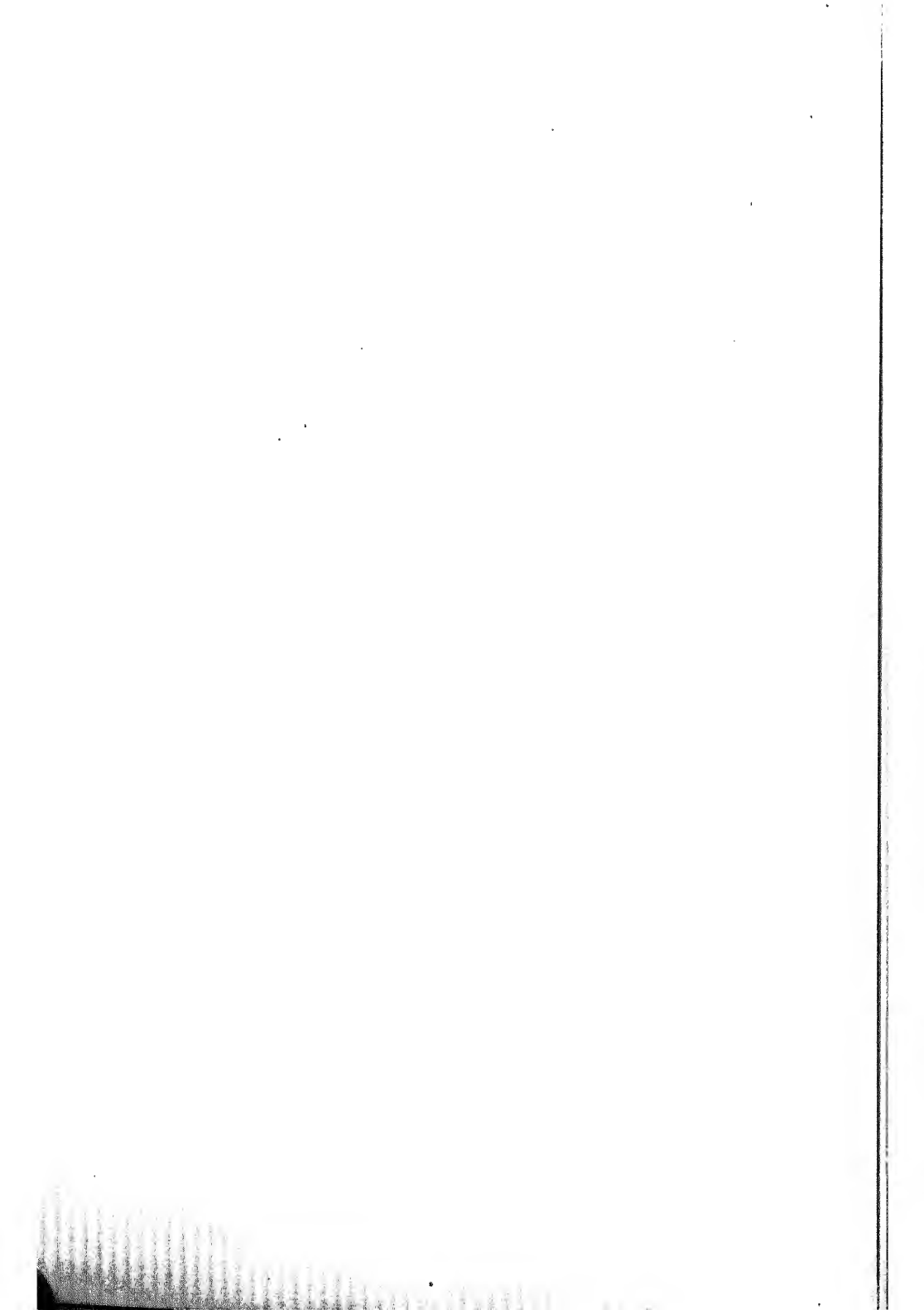
Except for this slight covering of drift back of the moraine the topography of the glaciated and the non-glaciated regions is precisely similar. The mountains are just as high and as sharp in one region as in the other, and in this region the glacier was certainly not an important agent of erosion. The Kittatinny and the Pocono mountains have the same general features and elevation in that portion of them once covered by the glacier as they have south of the limit of glaciation. The valley between them has the same topographical features above and below the moraine, except that in the glaciated region heaps of drift material have been dumped upon it.

The kames of Monroe county.

The most interesting of all the kames of Monroe county are the curious conical hills and short ridges of sandy drift



MORRIS KETTLE AND KAMES IN CHERY VALLEY, MONROE CO. PA. (SCENE REVERSED)



which lie along the centre of Cherry Valley between the moraine and the Delaware river. A remarkable series of conical hills of peculiar and characteristic topography either stand singly, or (more generally) are connected one with another by a low gravel ridge to form a series parallel with the valley.

Near the water gap these hills rise often over 200 feet above the river, and often inclose basin-shaped depressions or kettle-holes. They are most abundant between Stormville and the river.

Where the valley widens, just east of Stormville, two sets of kame-like ridges on either side of the valley form a V.

Short *tributary kames*, whose axes are at right angles to the main kame in the valley, appear opposite ravines or depressions in the hills bordering the valley.

Several of these *cross kames* may be seen in Cherry Valley south of Stroudsburg. They join the main kame on either side, running from the hills to the central kame.

The most important of these tributary kames is a steep ridge, 100 feet high, which, having all the contours of a moraine, starts from the *top* of Godfrey's ridge and descends in a straight line the steep slope to the centre of the valley, the general direction being about S. 40° E. This kame, while opposite no depression in the ridge, is directly in line with the N. and S. valley of Broadhead's creek on the northern side of the ridge.

It appears therefore that the stream which produced the kame flowed down the valley of Broadhead's creek and *over* the intervening ridge (300 feet high) into Cherry Valley; and, like that which made the kame along the valley, was probably sub-glacial.

A *buried kame* lies along the N. and S. valley of Broadhead's creek almost completely covered by subsequent deposits of terrace material. The *top* of the kame stands out of the level terrace plain which borders the creek at Stroudsburg and vicinity. A fine section of the buried kame at Stroudsburg shows its anticlinal structure and a *fault* in it caused by settling. (Figs. 3 and 4, plate 3, page 34.)

Another most interesting *buried kame* is in the valley of

McMichael's creek in Hamilton township where the top of the kame appears through the sandy terrace plain which covers the valley. The kame runs along the centre of the valley while the creek wanders irregularly through it.

Kames therefore are older than terraces.

Of the other kames and kame-like ridges of Monroe county it will be necessary here to refer to only a few.

Among other kames noticed in Stroud township are a series of short N. and S. kames which, appearing in Pocono creek below Stonington School, and at Snyder's Corners, and on McMichael's creek west of the cemetery, and near the house of D. Kortright, are probably portions of two kames which have been formed in the valleys of Big Meadow creek and Dry run. One of these, crossing at right angles the valley of McMichael's creek $\frac{1}{4}$ m. W. of Stroudsburg, is a remarkable ridge composed of three knolls.

The numerous rounded and elongated hills of sand irregularly heaped together at the village of Sand Hill appear to be a portion of the kame of McMichael's creek. Other kame-like deposits appear nearly as far W. as Brodheads-ville, as though deposited by the waters which drained the edge of the ice.

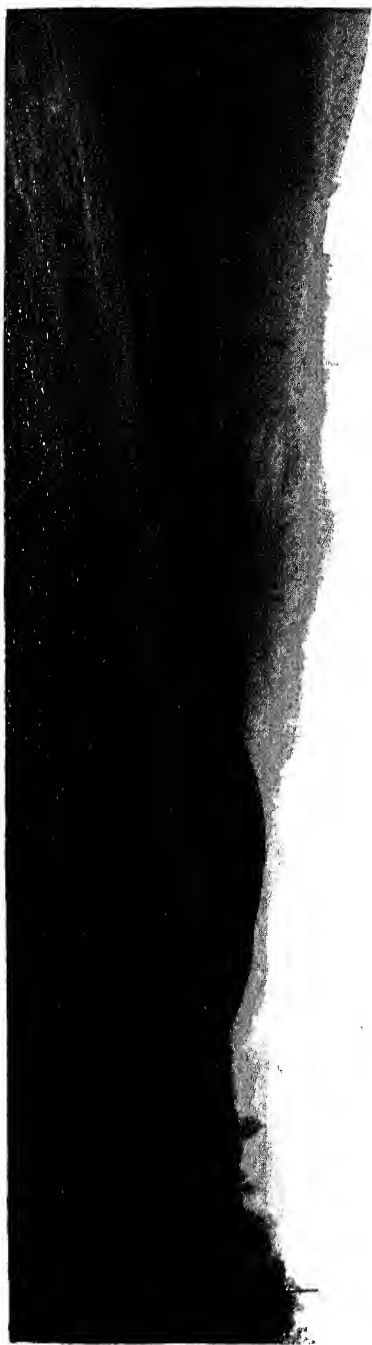
Kames also occur upon the summit of the Pocono plateau draining northward. Of these there may be mentioned the steep sharp ridges of sand near Tompkinsville, Tobyhanna township, which run northward, thus draining the glacial waters toward the Lehigh.

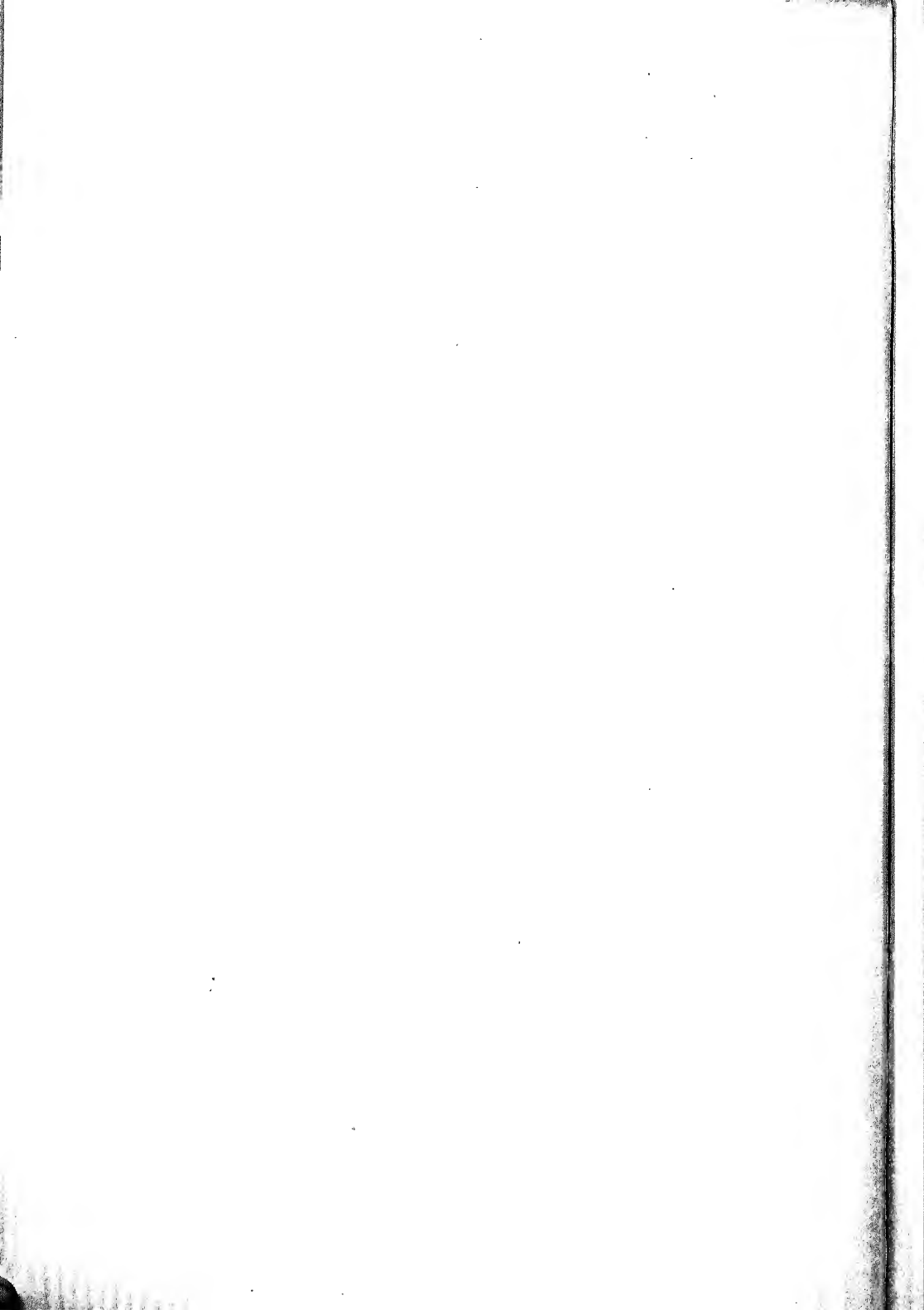
Hungry Hill on the Sullivan road appears to be a portion of a kame leading into the Tobyhanna creek; and the long sandy ridges west of Soxville are probably similar kames leading north-westward.

The kames which occur immediately back of the moraine are of especial interest. The hypothesis of their origin which most naturally suggested itself to the writer was that they were caused by sub-glacial streams of water which drained the melting ice along pre-glacial water-courses. All the facts observed confirm this hypothesis.

The contour of the kame hills with their hummocks and

JAMES IN CERRY VALLEY MORRIS ON PENNSYLVANIA





kettle-holes is precisely similar to that of the moraine and unlike that of any aqueous deposit in front of the moraine.

The frequent occurrence of till and boulders on the top of kames is further evidence of their sub-glacial origin.

The terraces of Monroe county.

Fine terraces may be observed in the vicinity of Stroudsburg. They are beautifully shown in the valleys of each of the creeks near that town; and also on the Delaware river above the Water Gap. In several places there are two terraces, flat on top, the one rising above the other. Those near Stroudsburg and the Water Gap may be due to an ancient obstruction in the gap backing up the floods from the melting glacier to form a lake of considerable extent.

That the terrace plains are of later formation than the kames is shown both on Brodhead's and on McMichael's creek, where, as already stated, the kames are partially covered by the terrace material.

In noting these beautiful terraces it is of interest to observe that the Indians recognized their meaning in the name which they gave to this region—*Minisink*, meaning "the water is gone." They have a legend that there was here a great lake which was finally drained by the breaking down of the natural dam which confined it and the tribe which first lived upon the land from which "the water is gone" were called "Minsies." Such facts may possibly prove of interest in connection with the researches now being made into the antiquity of man.

Glacial striæ in Monroe county.

The evidences of glaciation afforded by the striation, scoring, smoothing and polishing of exposed rock surfaces are very numerous throughout the glaciated portion of Monroe county. In more than forty localities glacial striæ were observed and measured by the writer. Those along the course of the moraine are the most interesting and will be first described.

In Hamilton township some remarkably fine exposures

of glacial striæ occur at Kemmererville nearly opposite the school-house. The striæ are upon Clinton red shale and bear S. 37° W. Immediately above this locality glacial action is very beautifully shown at the S. W. end of a hill of Clinton red shale, where for a space one eighth mile in length the rock is laid bare, rounded off and beautifully striated in parallel lines, the striæ being sharp and finely preserved. Huge boulders of hard white sandstone (Pocono), many of which are striated, rest directly upon the red rock and probably acted as the graving tools.

Great gouges, often a foot deep, have been scooped out of the soft red rock; and the rounded surfaces known as *roches moutonnées* are here finely shown. Standing upon these striated rock surfaces and looking up the valley in the direction of striation it is of interest to observe that the striæ point directly towards a wall of drift, which, extending across the valley, forms the back portion of the terminal moraine.

In Chestnut Hill township, near a school upon McMichael's creek one half mile S. of Phillipsburg, some ill-preserved glacial striæ occur upon Catskill sandstone, pointing about S. 73° W. This again is at right angles to the line of the moraine, a short distance to the west.

At the base of the Pocono mountain in Jackson township striæ were observed bearing S. 89° W.

The striæ in Pocono township also bear more westward than they do in townships farther removed from the moraine. Eight localities were observed in this township.

On the North and South Road, just S. of Stanhope, striæ run S. 61° W. A quarter mile south of Stanhope indistinct weather-beaten striæ on Hamilton flags run E. and W. at other localities upon the same road.

Great importance is attached to the *westward bearing striæ* just east of Pocono Knob; for they show the converging of the ice sheet toward an obstruction. Had they been produced by icebergs borne by a current they would have diverged. Farther east the striæ have a more N. and S. trend. Thus on the road from Tannersville to Henryville some rough, weather-beaten scratches on Catskill sandstone bear S. 55° W.; and on a second exposure, 20 feet distant,

S. 58° W. There is very little till in this region; these striæ, with an occasional transported boulder, are the only signs of glaciation.

Striæ were also observed in the extreme southern corner of the township about $\frac{1}{2}$ m. W. of Bartonville, where, close to the line of Jackson township, upon the road-side, the red shale shows well-preserved striations bearing S. 41° 30' W. A boulder of gray sandstone 10 feet in length lies close to the striated surface. Nearer Bartonville and at a lower elevation striæ may be observed upon Hamilton flags bearing S. 34° W.

Again at the eastern corner of the township, within a mile of Broadhead's creek and north-west of Spragueville, striæ upon the red sandstone bear S. 23° W.

Few striæ were noticed upon the Pocono plateau.

In the northwest corner of Tunkhannock township, on Tunkhannock creek close to the line between Carbon and Monroe counties, striæ on Catskill sandstone bear S. 50° E. They are all obscure and the direction given is only approximately correct.

In Tobyhanna township near Pocono Station on the Del. Lack. & West. railroad, there are indistinct striæ upon Pocono sandstone bearing S. 32° W. Some small fine striæ here run S. 12° W. but these last may possibly be *creep scratches*. The elevation here is about 1700 feet above the sea. The overlying till here is so filled with sharp fragments of Pocono sandstone that it has the appearance of a soil made of the decomposed and frost-broken rock in place.

Striæ occur immediately south of Forks Station (on the road toward Stanhope) upon Catskill sandstone, bearing E. and W. and S. 27° W., the first being the most distinct. These are in Paradise township at an elevation of 1525 A. T.

Some good striæ were noted at a flagstone quarry in Barrett township $\frac{1}{4}$ m. west of Oakland Station (at an elevation of about 1400 A. T.) bearing S. 36° W.

In Price township, upon the east branch of Broadhead's creek, a large smoothed surface of rock near the house of G. Haas is covered with excellent striæ, parallel to one another, bearing S. 23° 30' W.

Striæ occur at numerous localities throughout Stroud township and offer several features of interest.

Along Broadhead's creek they may be seen in several places. On the road leading along the west bank of the creek 4 m. north of Stroudsburg two sets of striæ occur on Hamilton slate; the older and more numerous bearing S. 37° W.; while another set more recent crosses the first in a direction S. 32° E. The latter are perhaps *creep striæ*.

Another exposure somewhat farther north shows main striæ S. 35° $30'$ W. with no cross striæ, proving the more recent striæ to be due to local causes.

A third exposure a few hundred feet south of the house of E. Bonyng gives S. 40° W.

Just above Spragueville on the W. side of the creek, at a point where a road crosses the railroad, there is a fine example of *roches moutonnées*, an outcrop of steeply-dipping red shale being laid bare and rounded on the north-western side, while striæ cross it diagonally S. 40° W.

About $\frac{1}{2}$ mile above the village on the east side of the creek, near the bridge at the forks of the creek, some striæ upon Chemung red sandstone run S. 27° W.

Striæ also occur in the valley of McMichael's creek $2\frac{1}{2}$ m. west of Stroudsburg, on the south side of the road near the house of H. R. Rausburg, on Hamilton shales, bearing S. 46° $30'$ W.

South of Stroudsburg there are several very interesting exposures of glacial striæ. Upon the S. side of Godfrey's Hill $1\frac{1}{2}$ m. S. of Stroudsburg upon the road from Stroudsburg to Stormville* is a fine example of *glacial striæ crossed by creep striæ*. An outcrop of Marcellus shale (at an elevation of about 560 feet above the sea) is covered by striæ bearing S. 6° W. Some large grooves point S. 8° W. These are crossed by a set of finer striæ bearing S. 20° E. The latter cut across the former, and are therefore subsequent. Since they point *down hill* they may be regarded as "*creep striæ*." Many of them are quite deep and well marked, and if not such creep striæ as were first noticed at Bangor, were certainly made by a subsequent and local movement

*Just below road leading to Foulke's boarding-house.

down hill either of the ice, of the till, or very probably of a mass of frozen till. A mass of frozen drift sliding down these soft shales would certainly be sufficient by the force of gravity alone to cause such striae. *Creep striae* may of course be formed at any time subsequent to the first general movement of the glacier. Whether the stones which engraved the striae were frozen in a mass of ice, or were loose, is of no consequence, provided that no force beyond that of gravity is needed to account for their movement. As will be seen after an account of the glacial striae of Pennsylvania, which pass up-hill as well as down regardless of topography, the force of gravity alone is quite inadequate to explain *their* formation.

Photographic Plate XIV of the locality shows creep striae crossing glacial striae at an angle of 39° :

A remarkably fine example of glacier scratches may be seen upon the top hill of Clinton red shale south of Cherry creek between the roads to Fox and Tatamy's Gaps. Here, near the house of R. Weiss, the rock for many hundred feet is laid bare, and the level polished floor of rock is covered by distinct and beautiful striae bearing S. 37° W.

Large boulders of limestone brought from Godfrey's Hill across the valley are perched upon the red rock. The striae vary from such as are as fine as a hair to deep grooves and great irregular *gouges*.

The whole north face of the Kittatinny Mt. is covered by striae having a S. by W. direction. *Table Rock* within a mile of the Water Gap House is covered by striae bearing S. 14° W. There is here a fine example of how cross scratches may be made by a single stone.

The scratches are of some depth and width and appear to have been made either by a stone hopping from one to the other, or by a sharp fragment turning over on its side while being pressed onward by the ice.

At this locality (Table Rock) the largest glacial groove seen in the State was observed. It is six feet wide and 70 feet long. It is a shallow groove running up hill at an angle of S. 17° W. It might readily be mistaken for the result of erosion along a cleavage plane, but that its regular

features, its symmetrical shape and especially the fact that it makes an angle of some 20° with the cleavage planes, distinguishes it. (See Photographic plate XV.)

Where the striae are well-preserved the *direction* of motion can frequently be determined by their shape. A remarkably fine exposure 2 miles southwest of the gap, where the whole summit of a hill of Clinton red shale is laid bare and smoothed off like a floor, and covered by beautiful striae bearing S. 37 W. shows the direction of striation very finely in the shape of its striae and especially its *gouges*.

In the most simple shape the larger end of the scratch is in the direction of motion. (See Fig. 1, plate 2, page 32.)

Others are jagged like saws, the teeth pointing towards the direction of motion. (See Fig. 2.)

But even more curious are the *gouges*, whose jagged ends point forwards. (See Fig. 3, 4.)

Observations upon the *direction* of the striae, which in different parts of the country varies from S. to W., offer valuable data to determine the motion of different portions of the glacier, and of the relations of such movements to the topography of the region and to the terminal moraine.

In principal valleys the striae conform approximately to the direction of the valley; while upon mountains they give the more general movement of the glacier.

It is established that in all cases striae near the moraine indicate a movement approximately at right angles to the line of the moraine. As the moraine curves N. N. W. or W. so the striae point W. S. W. or S. Thus, as the moraine lines N. W. in Cherry Valley, so the striae point S. W. As it lines N. around the Pocono mountain, so the striae in Pocono township point W. On the Pocono plateau where the moraine lines S. of W. the striae run E of S.

This fact is of importance in showing the method of formation of the moraine.

An unexpected fact was observed in relation to glacial action at the Water Gap. The Delaware Water Gap is a remarkable cut through the Kittatinny mountain, nearly at right angles to its range, and from top to base; the precipitous side walls being about 1200 feet high. It was nat-

ural to expect to find that a tongue of the glacier had gone through this gap; especially as the gap is only 10 miles N. of the southern limit of the glacier; which was not therefore as thick as farther north. It was found however that markings in the gap *supposed* to be glacial striae could be explained as the result of the smoothing action of trickling streams upon the alternating hard and soft strata of the Clinton red shale, producing a polished undulating surface slightly resembling glacial grooves.

The *real* glacial striae which occur near the Kittatinny and Water Gap houses at the base of the mountain, and on the path to the summit on the sides of the mountain, all point about S. 17° W. in a direction *obliquely across the mountain and the gap*; showing that the ice ascended the mountain (and crossed it) without having been influenced at all by the gap. No tongue of ice was projected through the gap. The gap was as it were *ignored* by the glacier, which filled it up with ice, but moved diagonally across it.

This fact is important in indicating the great thickness of the glacier close to its limit. It could not have been less than 1300 feet thick and was probably much greater.

Boulders in Monroe county.

Transported boulders often of considerable size and sometimes brought from great distances may be found in numerous places in the glaciated region of the county. Although there are numerous boulders in valleys in front of the moraine (carried forward by floods from the melting ice) they almost never show glacier scratches, and can thus be distinguished from the ice-borne boulders back of the moraine.

In Chestnut Hill township, upon a hill immediately in front of the moraine, on the road from McMichael's creek toward Effort, a few boulders of conglomerate and a striated pebble were found a quarter of a mile in advance of the moraine hills.

Of the numerous transported boulders in the glaciated region, composed as they are of almost every kind of rock, the most rare yet most important are those composed of gneiss and granite, which must have traveled from points

not nearer than the Adirondack mountains, 200 miles distant.

Of such boulders or *erratics* the most important is a boulder of hard gray *labradorite-syenite* (4 by 3 by 3 feet) close to the edge of the moraine one mile north of Lake Minneola. It lies upon the roadside close to McMichael's creek, at a cross-road to Effort.

Any theory attempting to explain the advance of the great glacier by additions to its front edge* is disproved by such an instance.

The boulders of gneiss found upon the Pocono mountain, a boulder of gray Adirondack granite containing magnetite found near Forks station in Paradise tp., at an elevation of 1550 A. T., and other similar boulders, all indicate a continuous motion of the glacier from northern latitudes.

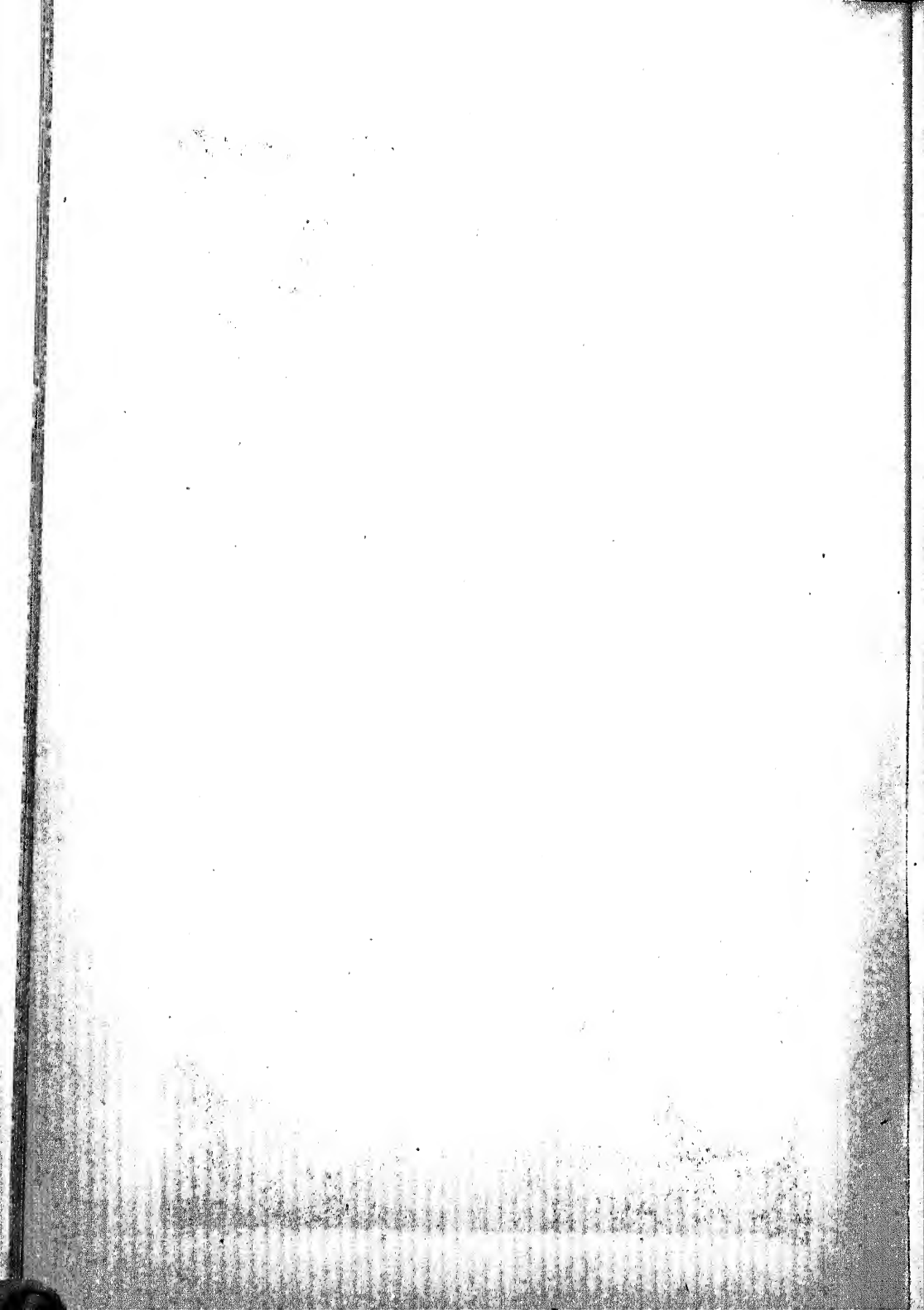
The largest boulders noticed have been derived from a sharp ledge of Helderberg fossiliferous limestone which borders Cherry valley. Large fragments have been lifted by the glacier from this ledge and deposited, in numbers, upon the north side of the Kittatinny Mt. at a *higher elevation* than the ledge from which they were taken.

Along the top of the ridge at Wolf Hollow $1\frac{1}{2}$ m. S. of the limestone ledge, boulders of limestone often 10 feet in diameter are abundant. Further south, at the base of the main Kittatinny Mt. on the road to Tatamy's Gap, lie similar immense boulders, two of them over 25 feet long, one of them 17 feet long, and others of great size, which have been carried across the intervening Wolf Hollow ridge.

But the most important boulder of all is one which the writer found at the very summit of the Kittatinny Mountain near the Water Gap. It is a boulder of the same limestone (fossiliferous Upper Helderberg Spec. No.) 6 feet in length. Lying at an elevation of 1200 feet above the river, it is proof conclusive that the glacier crossed the mountain into Northampton county.

Smaller boulders of Clinton red shale, Hamilton flags, etc. some of them covered with fine glacial striæ, were

* Recently advocated by W. J. McGee. Proc. Amer. Ass. Adv. Sc. 1880.



found at different places along the summit of the mountain between the Water Gap and Fox's Gap; adding their testimony to the passage of the glacier across the mountain, and to its ability to lift boulders from a lower to a higher elevation.

The transported boulders found in the moraine west of the Fox Gap have already been noticed.

In noting the distribution of boulders throughout the county it was observed that they were generally more numerous on the side of a hill facing the coming glacier.

Mountain moraines in Monroe county.

Of the other glacial phenomena of Monroe county some of the most noteworthy are the great heaps and ridges of *unmodified till* which occur at a number of places along the base of Pocono mountain. These accumulations have often all the characteristic topography of the terminal moraine, and in the course of exploration were frequently confounded with it. They are probably true moraines, of local extent, and may be called provisionally *mountain moraines*.

They are seen in several places upon the line of the Del. Lack. and Western R. R. A moraine of this character forms high drift hills and is nearly a mile in length at Henryville, Paradise township. Like the terminal moraine it is covered by large boulders and can be traced continuously for several miles. It is perhaps a continuation of this same moraine which, made of till and of Pocono sandstone, covered by boulders often 20 feet long, passes through the forest in the southern part of Barret township.

The drift accumulations along the base of the mountain in Paradise township between Oakland and Forks, cut through by the railroad, are probably of similar nature.

Resumé of facts.

Reviewing now the data collected in Monroe county there are several conclusions which deserve attention.

(1.) The line of the moraine from the Kittatinny mountain across the Monroe county valley to the Pocono plateau is

in no sense a water line, nor could it have been determined by floating ice.

(2.) The fact that no tongue of ice was protruded through the Delaware Water Gap, and that the ice sheet projected westward only a few miles down the broad valley between the Pocono and the Kittatinny mountains, indicates its immense size, and its independence of the topography.

(3.) Neither on the Kittatinny ridge, in the valley north of it, nor upon the Pocono plateau, did the moraine come to rest against any *barrier*.

(4.) The boulders of labradorite, gneiss and granite prove its continental character; and disprove any assumption that the glacier advanced by additions to its rim, or by the confluence of local glaciers.

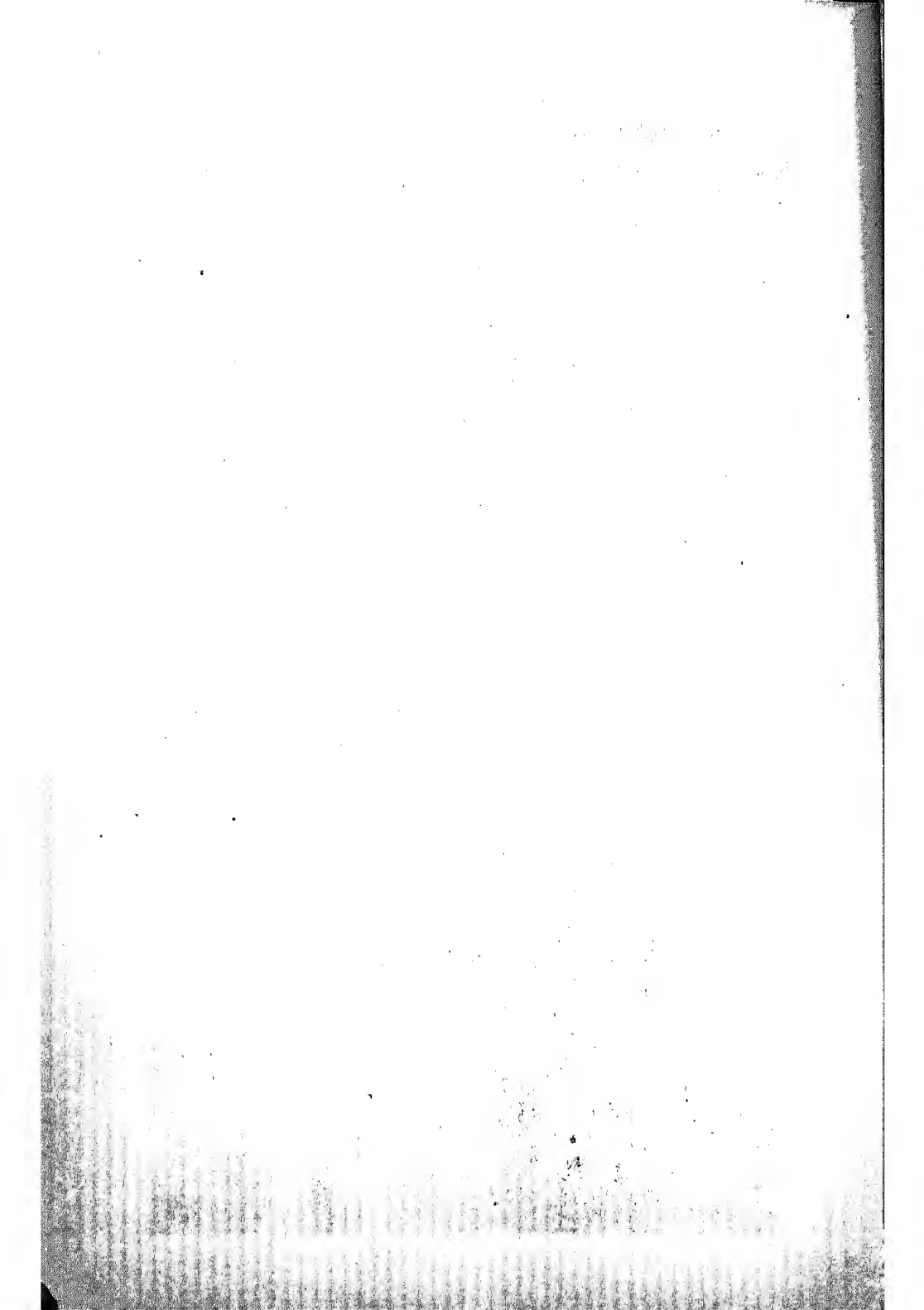
(5.) The fact, that upon the Pocono plateau, 2000 feet above the sea, the moraine accumulations are developed precisely as they are at the level of the sea, shows the continuity and the uniformity of action of a continental glacier.

(6.) The fact that the striæ run always at right angles to the moraine speaks for a single continental glacier.

(7.) Important evidence that the striæ are the result of the movement of a continental ice-sheet is offered by the change in the direction of the striæ east of Pocono Knob, which stemmed its forward flow like the prow of a ship, the ice closing in around the obstruction, and pressing against it on three sides.

(8.) Numerous kames along valleys leading backwards from the moraine indicate an important *sub-glacial drainage* which when fully understood may throw much light upon deposits of stratified drift regarded by some geologists as evidences of great changes of sea level.

(9.) That the erosive power of the glacier was slight along its southern edge is shown in the uniform character of the topography both of mountains and valleys in the glaciated and non-glaciated regions. The straight narrow ridge of the Kittatinny mountain extends from the Delaware to the Lehigh with no apparent difference in appearance or in elevation; while the Delaware Gap and the Lehigh Gap are closely similar in shape. Yet the glacier crossed



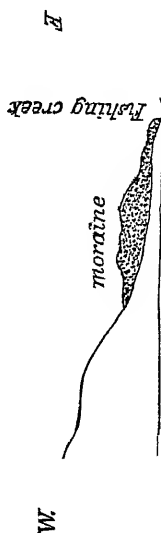
the Mountain and Gap with scarcely an appreciable effect upon their topography.

There is no proof that the glacier scraped off as much as 100 feet from the top of the mountain. Cliffs 70 feet high in front of the moraine upon the Kittatinny mountain may serve as a measure of the amount of erosion.

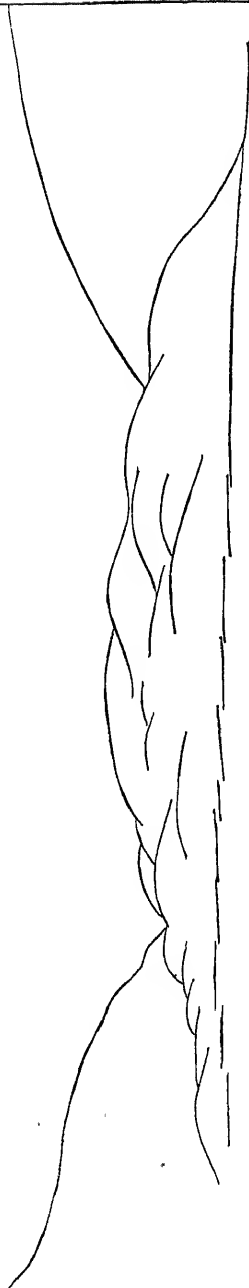
The transported boulders of the glaciated region were probably already loose when lifted from their original outcrop. Almost every block of limestone that was taken from the Helderburg ridge in Cherry Valley can be traced to its destination; and Godfrey's ridge has certainly suffered but slightly from the glacier.

(10.) Evidence both of the thickness of the glacier and its great impetus, however given, is afforded by the fact that it flowed upwards and across the sharp ridge of the Kittatinny mountain, although close to its extreme southern terminus.

92 Z



Edge of moraine N. of Cole's mills, Columbia county.



Looking S. at back of moraine filling valley at Cole's creek P.O. Pa.

CHAPTER VI.

In Carbon County.

A very small portion of Carbon county, only the upper half of its most northern township, has been glaciated.

Kidder township through which the moraine passes is a wild, heavily-wooded region with few roads and very rare exposures.

The moraine crosses the Tunkhannock creek and enters the eastern edge of Kidder township about a mile east of Big pond. It here forms low rounded hills of characteristic shape. Going westward it passes about a half mile north of Grass lake and close to Round pond, Big pond, Moses Wood pond and Mud pond. While some of these ponds are probably enclosed in the moraine, others such as Grass lake and Big pond appear to have been formed by the moraine having dammed up their northern outlets, as was the case with Long pond, Monroe county.

The moraine near Round pond is nearly 700 feet above the Lehigh at Hickory run, the point where the Lehigh is crossed by the moraine.

One mile south of Sailorsville, on the road from Sailorsville to Albrightsville, the moraine appears as low hills covered by striated boulders. From this point it skirts the north side of Pine Hill and descends westward to the Lehigh at the mouth of Hickory run.

At the fork of roads $2\frac{1}{2}$ miles east of Hickory run station (500' above the station, or 1500' A. T.,) close to the southern edge of the glacial drift, Pocono sandstone, exposed in bare

ledges, snows faint glacial grooves, generally an inch wide and about a foot long, bearing S. 2° W.

The extreme edge of the drift is immediately south of this point although not marked by a distinct moraine. The *till*, which contains striated pebbles, (Spec. No.) and which is shown in an exposure to be at least 6 feet deep, here comes to an end on the northern slope of a hill near an old saw-mill; beyond which are bare, unglaciated out-crops of Pocono sandstone.

On the higher ground known as Pine Hill, south of the moraine, not a single transported or striated pebble is seen, and the soil becomes sandy, being formed from the decomposition in place of the underlying sandstone. The rounded pebbles of quartzite and sandstone, (some of which are 3 inches long,) which occur south of the moraine have been weathered out of the coarse conglomerate, and should not be mistaken for drift. The sandstone itself also weathers into rounded forms which might be mistaken for transported boulders.

The point where the moraine crosses the Lehigh may be distinctly seen by anyone traveling either on the Lehigh Valley or Lehigh and Susquehanna railroads. The contrast between the glaciated and the non-glaciated regions is strongly marked.

Notwithstanding the fact that in the narrow gorge of the Lehigh the moraine has been completely washed away, the character of the banks of the river and of the gorges occupied by tributary streams is sufficient to indicate its position.*

* The descent of the Lehigh river through the gorge is so rapid, and the upland country drained into it is so large, and pours so vast a body of melted snow water through it every spring, that no loose materials can remain in the gorge except for a few years *in transitu*.

The Lehigh Valley Railroad at *White Haven* is 1148'; at *Hickory run* (5 miles below) 1016.5; at *Rockport* (5 miles below) 906.5; at *Pennhaven junction* (6 miles below) 705.5; at *Glen Onoko* (5 miles below) 591; at *Mauch Chunk* (2 miles below) 544.4 A. T.

From *Hickory run* down to *Glen Onoko* (where the gorge ends,) 16 miles, the river bed lowers itself 425' = $26\frac{1}{2}'$ per mile.

Dams 60 feet high were built by the Lehigh Canal Navigation Company. But no engineering skill could save them from destruction. Nor can the largest masonry resist the exceptionally violent floods which recur at intervals of a few years.

South of the moraine the rocks bordering the picturesque gorge of the Lehigh are bare or covered with sharp fragments torn off by frost. Pulpit rocks occur at Stony run.

The numerous gorges formed by tributary streams contain no gravel and are occupied only by fallen rocks. Thus, Leslie's run and Muddy run, though but a mile or two below the drift-covered area, enter through gorges perfectly free from drift. Although there are boulders in the river bed, and patches of boulder-bearing clay frequently lie high up on the banks, (as high as 180 feet above the stream,) these cannot be mistaken for the true glacial drift north of the moraine.

But entering the glaciated region the character of the river banks is suddenly changed. A covering of gravel and large rounded boulders appears on either side; the drift has filled the gorges occupied by tributary streams and transformed them often into shallow valleys; and terraces and ridges of gravel appear in the bottom of the river valley itself.

Thus, opposite both Sandy run and Hickory run the railroad passes through cuts made in banks of drift 20 feet deep. In the valleys of both of those streams are banks of drift 50 feet high, containing large boulders, of varied lithological composition, many of them striated.

A little farther north, near the Lehigh Tannery, where the banks are not so steep, kame-like ridges of water-worn drift occur in the valley; while rounded drift hills are seen on either bank.

The distinctive characters of a glaciated and of a non-glaciated region are therefore readily recognized.

The moraine, now washed away, appears to have crossed the Lehigh just north of the dam in the river, near the upper corner of Lausanne township, and about a quarter of a mile south of Hickory Run station.

The course of the moraine in Carbon county is of interest in that it exhibits a descent in an unbroken line from the summit of Pocono mountain to the bottom of the gorge of the Lehigh river—a vertical descent of over 1200 feet.

Several localities in the vicinity of the moraine exhibit

glacial *striæ*. Near Sailorsville the quartz pebbles in a conglomerate are planed off, and gouges of curious shape replace the *striæ*. (See Fig. 4, page plate 2, page 32.)

East of Hickory Run station, on the road up the creek, till and striated boulders abound. Some indistinct *striæ*, running about S. 62 E. occur on the north side of the creek $\frac{1}{4}$ mile below Saylorsburg.

Striæ also occur $\frac{1}{4}$ mile E. of Hickory Run village, on the road to Albrightsville, bearing S. 45 E. but are poorly preserved; being on the downward slope of a rock they are probably somewhat deflected from the general course of the ice movement.

The most interesting *striæ* are some which, covering a steeply inclined surface of Catskill red shale just back of Hickory run station, are crossed by what the writer has called *creep striæ*. The glacial *striæ* and the *creep striæ* may be seen on the same surface. The glacial *striæ* running diagonally *up* the steeply inclined surface of rock, bear S. 40° W., being deflected from their true course by the steep inclination of the surface over which they run. They vary in direction from S. 22° W. to S. 41° W. Their direction from below *upwards* is finely shown by their shape being blunt at their upper extremity.

Fig. 5, page plate 2, page 32, is a half size drawing of one of these upward scratches $6\frac{1}{2}$ inches in length.

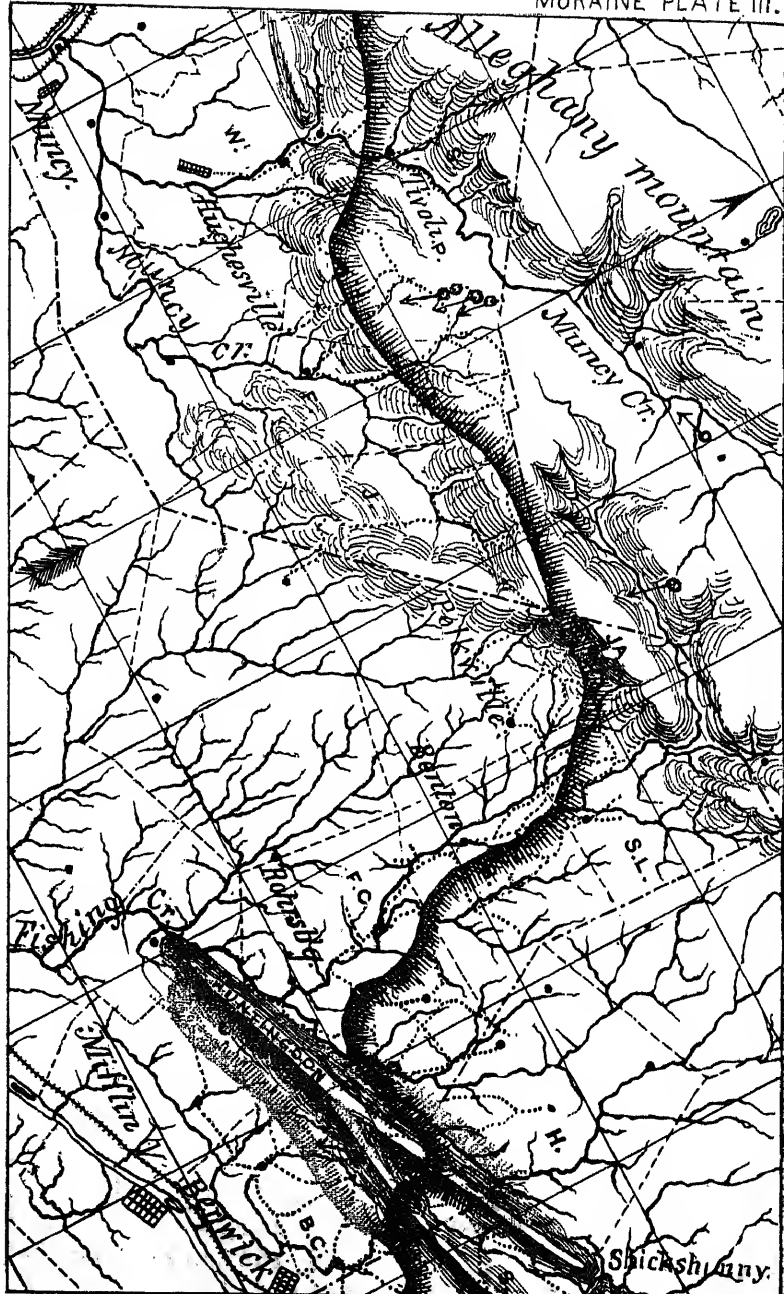
These *striæ* are crossed by *another set* of much smaller and finer *striæ* which run vertically *down hill* bearing N. 25° W. to N. 33° W. These last are evidently *creep striæ* caused by the heavy till sliding down hill by the action of frost and gravity and scratching the soft rock below. In fact a heavy body of till still remains on the upper portion of the rock ready at any moment to slide down the same declivity. The *creep striæ* also show the direction of movement by their shape being thicker below. Specimen No. — taken from the spot and deposited in the collection of the Geological Survey shows the crossing of the two kinds of *striæ* and the direction of motion of each.

The *creep striæ* run N. 25° W. or directly down hill over the steep N. W. slope of a smoothed rock; while the glacial

striæ run S. 40° W. or diagonally up hill; and the angle between the two kinds of striæ is 115°. The elevation above the ocean is 1016 feet.

Of the *kames* of Carbon county there should be mentioned the long ridges of stratified drift, which, close to and along the Tobyhanna creek, run west of north and indicate that the valley of the Tobyhanna was a channel which drained the edge of the glacier *backwards* into the Lehigh.

South of the glaciated area there were other drainage channels. Thus near Albrightsville, along the valley of Muddy run, are deposits of clay, gravel and water-worn boulders at an elevation of 1700 feet above the sea. These deposits are confined to the vicinity of the creek and indicate an ancient drainage channel from the glacier south-westward. These aqueous deposits, consisting of an impure clay holding water-worn boulders, appear to be identical with the boulder-bearing clay south of the Wind Gap in Northampton county, and appear to have been formed like that by the first melting of the ice at the time of the greatest southern extension.



CHAPTER VII.

In Luzerne County.

The southern portion of Luzerne county, across which the moraine passes in an undulating line bearing somewhat north of west, is occupied by a series of mountain ridges ranging S. 60° W.

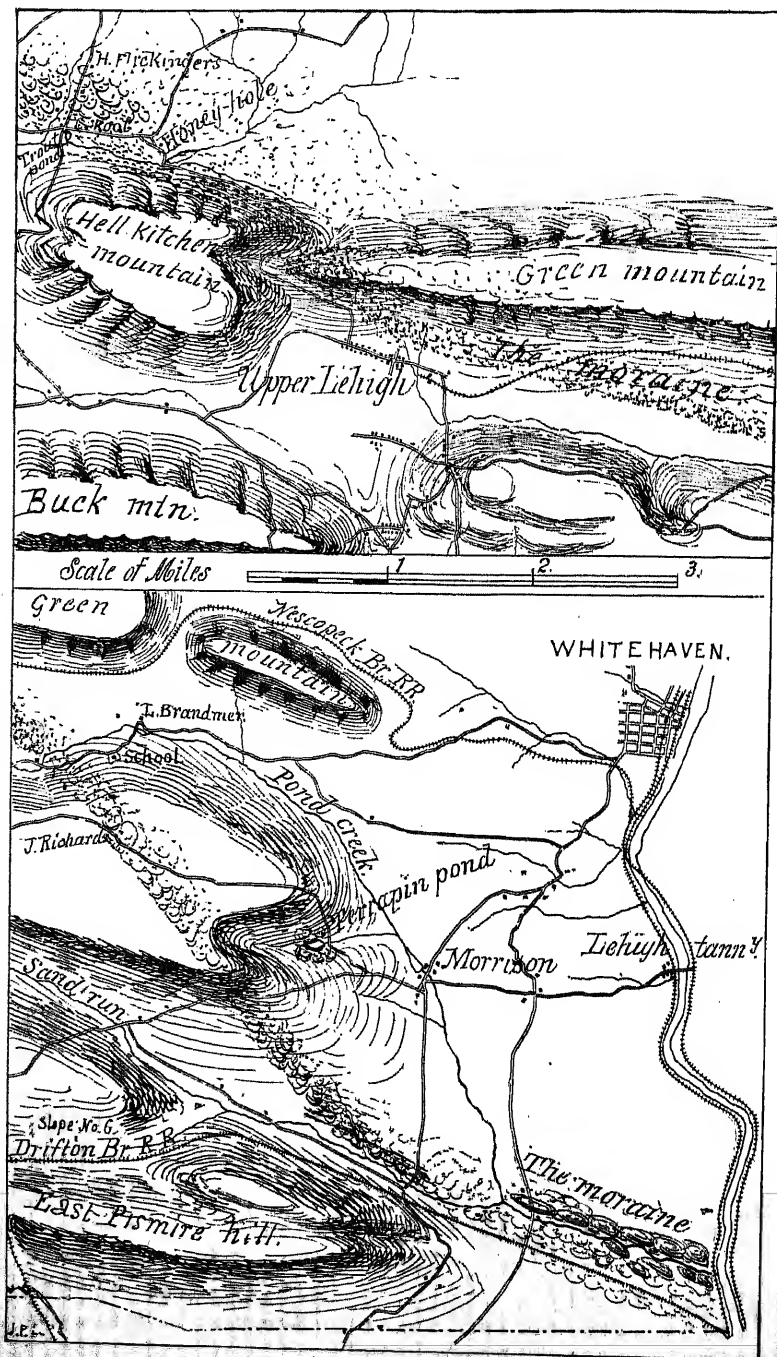
It is important to notice that the moraine is deflected *northward* as it approaches the south foot of each ridge, and after having crossed the summit bends nearly at right angles *westward*, so as to slope down the north side to the base, and then along the base of the mountain, before resuming its general northwestward course across the valley.

The general movement of the ice in Luzerne county as shown by the fine striæ upon the summit of Penobscot knob (2220 A. T.) was S. 10° W.—while the general direction of the terminal moraine from Hickory run on the east to Beach Haven on the west is N. 80° W.—two directions precisely at right angles to one another.

Course of the moraine in Foster township.

The moraine enters Luzerne county at the south-eastern corner of Foster township south of Sandy run.

Glacial till 25 feet deep occurs on the Lehigh near Drifton Junction at the mouth of Sandy run, a good section being exposed by a cutting of the Lehigh and Susquehanna railroad. Where a portion of the till has slid off, the bare rock is exposed so as to show shallow scratches bearing S. 15° E. As these run down hill it might be conjectured that they



were creep scratches of post-glacial age but for the fact that the rock is very hard and its slope gentle. They are probably true glacial striæ having a bearing at right angles to the moraine at that point.

Drifton Branch railroad ascends Sandy run, and for a mile or two keeps close to the edge of the moraine. Farther west the railroad leaves the creek and the moraine. The latter turns northward at a point nearly four miles west of the Lehigh. The road which runs south from Morrison P. O. crosses the moraine and the railroad together.

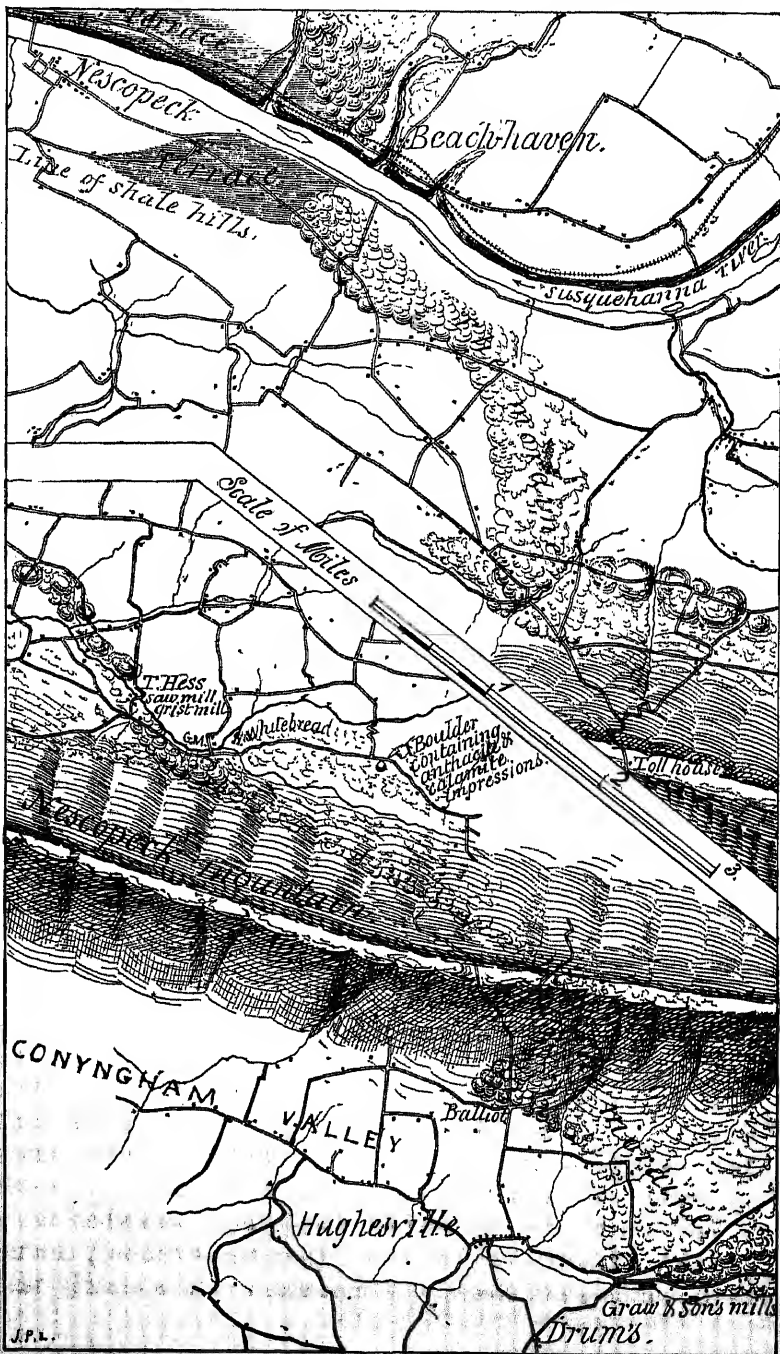
From the road on the mountain side immediately south of the railroad one can look down upon the moraine in the valley and see it for nearly a mile westward.* This is a good place to observe the characteristic topography of the moraine. It appears as a series of low, rounded, knob-like hills of drift, irregularly distributed, and often connected with one another by low ridges. The wood road leading from this point to Eckley keeps upon the edge of the moraine for about two miles, and although necessarily a rough road to travel, is an excellent one upon which to observe the moraine with its kettle-holes, ridges, boulders and striated pebbles.

South of the moraine there appears to be no drift whatever. Not a single transported pebble occurs for example in the vicinity of Jeddo, Eckley, or Upper Lehigh.

Somewhat more than a mile S. W. of Morrison the moraine turns northward towards a mountain which it is about to ascend. Immediately back of the moraine kame-like hills and ridges of sand are frequent. At the foot of the mountain one mile west of Morrison these sand hills are well developed and of characteristic contour. *Terrapin Pond* ($\frac{1}{2}$ m. west of Morrison) is a kettle-hole filled with water. The sand hills here (which are excavated for sand) appear to form a true *kame* leading from the moraine eastward to the Lehigh at the Tannery.

Upon the road which leads from Morrison to Upper Lehigh, at a point about $2\frac{1}{2}$ miles west of Morrison, and at an

* This mountain is East Pismire Hill, which bears upon its top the anthracite coal basins worked at Eckley, Jeddo, &c.



elevation of 1600 feet above the sea, the moraine can be distinctly traced as it runs across the top of the mountain. It consists of several low parallel ridges bearing N. 20° W. at right angles to the motion of the ice.

East of the moraine upon the mountain are till and boulders; while west of it they are completely absent. Boulders of Pottsville conglomerate (some over ten feet in length) lie upon the northern slope of the mountain.

Nowhere in the State is the moraine more sharply defined than at this point. So sharp is the contrast between the yellow till of the moraine and the red shale soil of the mountain that the southern limit of the glacier can be determined within a few yards. And since the deposit left by the glacier at this high point has not been modified by the action of water it is almost possible to stand with one foot upon the glaciated and the other upon the non-glaciated ground.

One third of a mile west of the village of Pond Creek the moraine forms low hills where it crosses the road from White Haven to Upper Lehigh. (Specimen of striated pebble No. —.)

The moraine now runs west along the slope of the mountain, entering Butler close to the corner of Denison township.

Course of the moraine in Butler and Hollenback townships.

In Butler township it runs for several miles along the north-west slope of Hell Kitchen mountain, and is well shown one mile north of Upper Lehigh on the road to Honeyhole and Butler valley. The moraine here rest upon the mountain about half way down and (as shown upon the newly cut road) has a sharply defined edge.

Passing just south of the place called Honeyhole the moraine descends to the level of Conyngham valley. At a point about one mile east of Hughesville, where the moraine forms low hills in the centre of the valley, it turns again northward towards the Nescopeck mountain. It passes to the north of Hughesville, appearing somewhat more than a mile north of the town; then turns directly northward and ascends Nescopeck mountain. It is clearly seen

as it crosses the very summit of the mountain on the road from Hughesville towards Dorrance, being recognized by numerous transported and striated boulders. (Spec. No.)

Just back of the moraine, on the northern slope of the Nescopeck mountain a few hundred feet from the summit, are glacial striæ on Pocono sandstone bearing about S. 54° W. These are in the southwestern corner of Dorrance township on the road leading towards Hobbie.

Fine striæ upon a lateral face of rock appear here.

After having crossed the mountain the moraine bends west and gradually descends the northern slope through Hollenback township. It makes distinct hills of drift in a nearly straight line for six miles along the base of the mountain.

Striated pebbles and large erratics are abundant in Hollenback township. Rounded drift hills occur along the Wapwallopen creek.

Course of the moraine in Nescopeck township.

The moraine enters Nescopeck township near its southeastern corner and, leaving the base of the mountain, passes north-west within a mile of the village of Summerville to the East Branch of the Susquehanna river at a point opposite Beach Haven. On the banks of the river the moraine forms rounded knolls of till which rise through the stratified drift bordering the river. A plain of stratified river drift, similar in all respects to that of the Delaware, extends from the moraine to the town of Nescopeck, which is built upon the lower of two terraces.

Course of the moraine in Salem township.

On the opposite side of the river the moraine appears about half a mile below Beach Haven in Salem township. It forms hills covered by striated boulders, and is best recognized at the distance of about a mile back from the river, where it is less modified by water action. A great level plain of stratified drift, which forms a terrace 75 feet above the river, and which is a mile broad and four miles long, abuts against the moraine at this point, having been formed at the time of the final melting of the glacier. In fact, at

every place where a river crosses the moraine and where recent floods have not washed all deposits away, there is found a *sandy, stratified gravel*, often worn into level-topped *terraces* which are highest near the moraine and become lower or disappear farther down the river.

The moraine hills (Spec. of striated boulder No.) rise out of this plain of river gravel at the first road west of Beach Haven. The Cemetery is placed upon the side of the moraine, and the town of Beach Haven is at its base. The moraine hills extend for a mile or more up the river. The front line of the moraine extends north-westward in Salem township, winding up over the hills, and being often recognized at a distance by the boulders which the glacier has dropped upon them, until, approaching the line of Columbia county, it turns nearly at a right angle and enters Briar Creek township, Columbia county, at a point $1\frac{1}{2}$ miles N. E. of Foundryville.

One of the most important facts exhibited by the moraine in Luzerne county is that, in descending from the Nescopeck mountain to the Susquehanna valley (a valley more than a thousand feet lower than the mountain and seven miles in width) it does not swerve from its course. The moraine is in no respect a water-level. No flood or inland lake covered by floating ice could have been bounded by such a shore line.

That the accumulation of drift here called the terminal moraine was not formed by opposing currents of water as a sort of eddy-bank, is shown by the absence of all evidences of aqueous action on its southern side.

Nor is there any evidence that the glacier projected any tongue of ice down the Susquehanna river. The level-topped terrace of stratified sand and gravel which rests against the moraine below Beach Haven is of an entirely different character from the moraine. The moraine is an impure clay filled with rounded and angular boulders and fragments, many of which show striations. The stratified drift, on the other hand, consisting of loose gray sand and

gravel, the pebbles of which are all smooth and water-worn, often flattened and showing striations, is evidently the result of water action alone.

Glacial striæ in Luzerne county.

North and east of the moraine, Luzerne county everywhere shows signs of glaciation. The glacial striæ here, as probably in every mountainous district, may be considered as of two kinds: *upper striæ*, or those made upon elevated peaks by upper portions of the glacier; and *lower striæ*, or those made in valleys and ravines, where the local topography deflected the lower part of the ice. These two kinds of striæ, the one indicating the general, the other the local movement of the ice, have already been pointed out in Monroe county, and are found throughout the entire glaciated area of the State.

Of *upper striæ* the most instructive are those upon the summit of Penobscot Knob, bearing S. 10° W. Striæ occur in abundance over different portions of the mountain closely conforming to the same direction. They were noticed at elevations of 1990 feet, 2075 feet, 2088 feet, 2150 feet and upon the summit at 2220 feet.

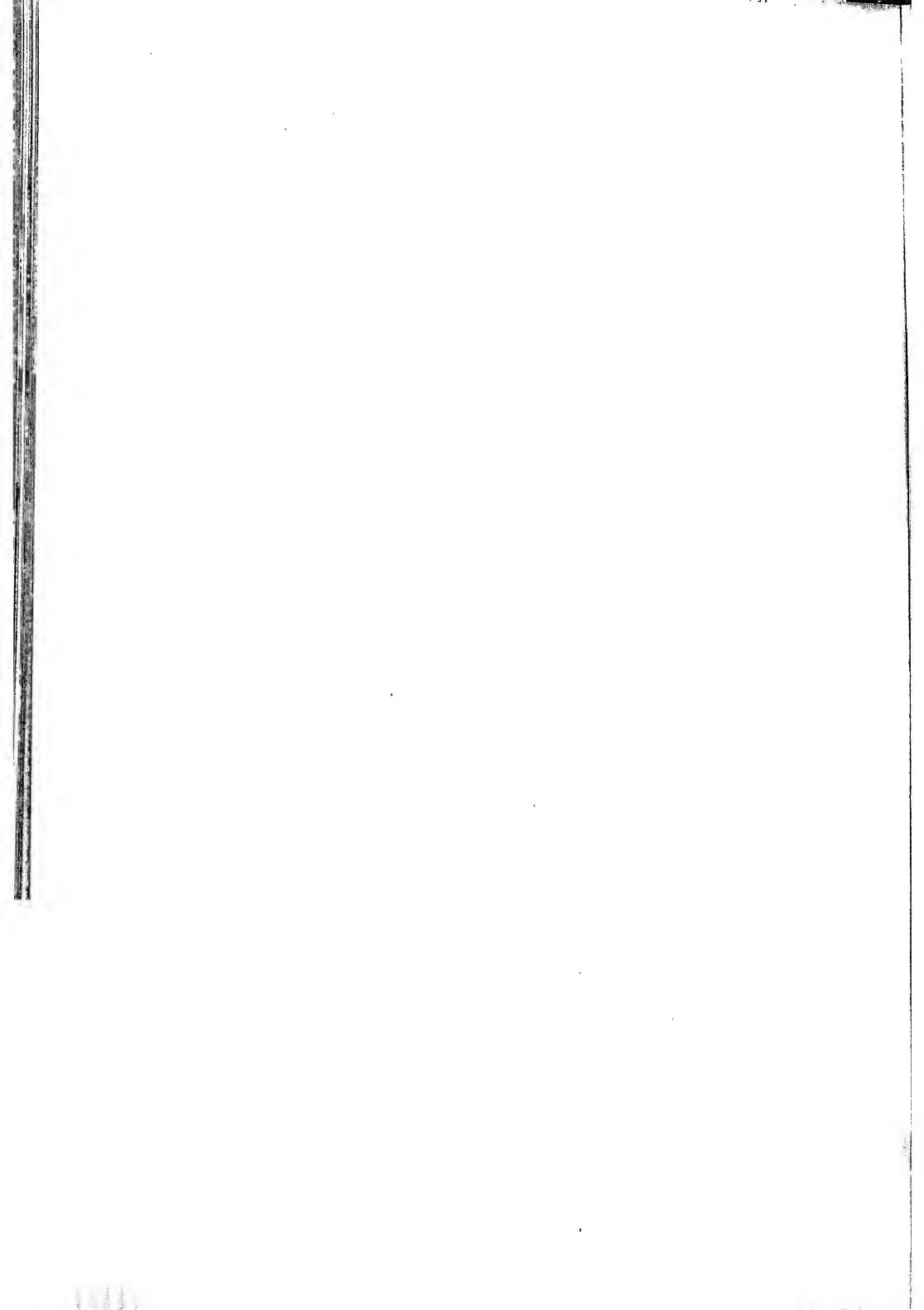
At 2088 (by aneroid) the writer found a fine transported boulder of white Pottsville conglomerate (No. XII) measuring 9 by 6 by 4½ feet. It rests upon an outcrop of Catskill sandstone hundreds of feet higher than any outcrop of the conglomerates around the Wyoming coal basin.

Penobscot Knob is only nine miles north of the moraine and its glaciation proves the great thickness of the ice near its edge. (See page 14 above.)

In contrast with the *higher striæ* of Penobscot Knob are the *lower striæ* near White Haven. About half a mile north of that town, on the Lehigh Valley R. R.; a fine embossed surface of Catskill sandstone is covered by striæ which can be seen from the car windows. Their mean direction is S. 35° E. This direction although determined by the topography of the valley is approximately at right angles to the moraine at Hickory run five miles distant. Nearer White



BOULDER OF POTTSVILLE CONGLOMERATE ON THE CREST OF PENOBSCOT MTN.
LUZERNE COUNTY, PA.-- LOOKING WEST. (PICTURE REVERSED.)



Haven, at Jerusalem Siding, (elevation 1160 feet) are obscure striæ bearing about S. 10° W.

Striæ are numerous in the northern portion of the county.

At Pittston close to the L. & B. R. R. Junction they run over coal measure sandstone outcrops S. 46° W. Nearer the middle of the town others have the same direction. As this is also the direction of the valley of the East Branch of the Susquehanna at this place the striæ may be regarded as lower or local striæ.*

An interesting exposure of *roches moutonnées* occurs at Taylorville station on the D. L. & W. R. R. A hard carboniferous sandstone is rounded off and finely sculptured by glacial action. Drift overlies a portion of it; but the exposed surface is covered by fine striæ very noticeable from the cars. Their general direction is S. 53° W. closely conforming therefore to that of the valley of the Lackawanna river in which they lie. Many of the striæ are an inch in width and several feet in length. Occasional striæ clearly show the direction of flow by their wedge-like shape.

Fig. 6, page plate 2, page 32 above (reduced one half) represents a scratch eight inches long which while tapering to a point at its N. E. end is blunt and flat at its S. W. end, where it is one half an inch broad and much deeper than elsewhere.

It occurs upon the E. side of a vertical face of rock. The rock is embossed into curved surfaces, and the striæ upon different sides of such surfaces vary some 5° in direction. On vertical faces the striæ ascend, in the direction of flow, at angles to the horizon varying from 1° to 25° according to the direction of the vertical face. On a vertical face whose strike was S. 45° W. the striæ sloped 5° to the N. E.; on a vertical face bearing S. 77° W. they sloped 20° .

*[Many years ago Professor H. D. Rogers pointedly called attention to the fact that all the scratches in the Wyoming coal basin were directed in a grand curve, from the gap at Pittston, around (south of) Wilkesbarre, to the gap at Nanticoke; the topography of the valley governing the movements of the scratching agency. This he at first supposed to be a deluge of water, but afterward recognized as moving ice.—J. P. L.]

Fig. 1. Sections of kames near Lackawanna.

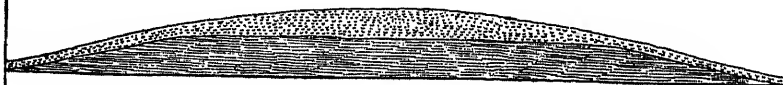


Fig. 2.

Chapter V.

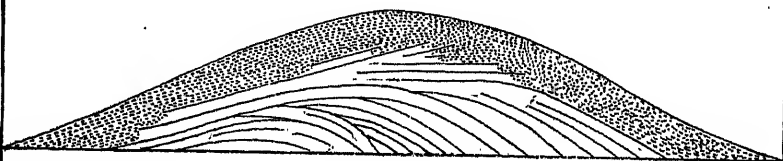
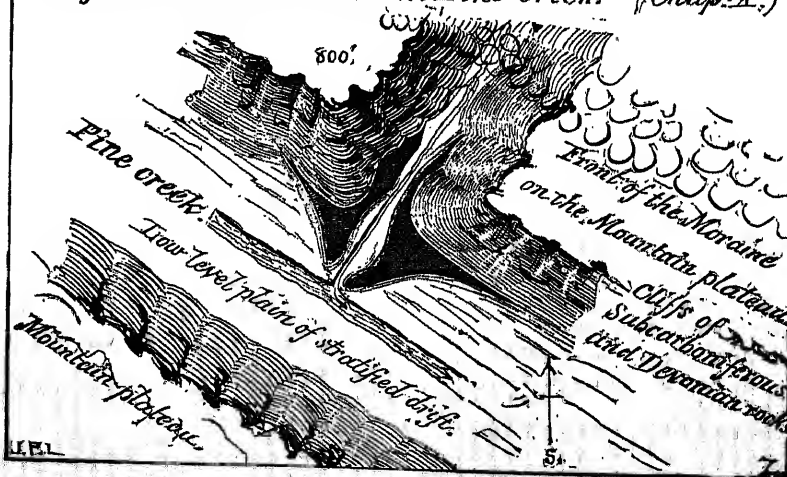


Fig. 3. Stratified-drift-plain near Berwick. (VI)



Fig. 4. A terrace-delta on Pine creek. (Chap. X.)



The following law might be formulated from the facts here observed: On a vertical face the slope of striæ increases with the angle made by such vertical with the direction of flow. It follows that the true direction of the ice flow is engraved only upon horizontal surfaces.

Kames and Terraces.

Among the glacial phenomena of Luzerne county the long ridges of stratified sand and gravel, and the terraces along the river are important features. Some of the most typical deposits of this kind occur along the Lackawanna river between Scranton and Pittston.

At Scranton a *terrace* rises nearly 100 feet above the river. About five miles below, it is divided into two flat-topped terraces, the upper of which is much the higher. Both terraces have sharp escarpments and appear to have been cut through by successive diminutions of volume in the river.

Apart from the terraces is a *peculiar ridge of stratified material* which runs parallel or nearly so with the river, and which appears (sometimes back of the terraces and sometimes in front of them) in the very centre of the valley.

At Scranton, on the south side of the river, this ridge rises some 65 feet above the terrace, and contains irregular depressions, or *kettle-holes*.

Below Moosic the ridge appears in the centre of the valley, rising nearly 200 feet above the river.

Both above and below Taylorville the ridge is distinctly seen on the southern side of the river, and shows characteristic topography. Good sections are exposed on the north side of the river immediately below Taylorville, and southwest of Lackawanna, and on the south side of the river one mile N. E. of Lackawanna, and at the junction of the Lackawanna and Susquehanna rivers. The sections show the ridges to consist of horizontal or irregularly stratified layers of gray sand, overlaid unconformably by coarse gravel containing boulders.

The sections, shown as Figs. 1 and 2 on page-plate 15, are seen 1 mile north of Lackawanna on the south side of the river.

The first section shows a kame having horizontal sand layers; while the second illustrates an anticlinal structure of the sand more commonly seen.

Other sections show fine *flow and plunge* structure in the layers of sand.

The boulders which are frequently perched upon the ridges are rounded by water action. Sometimes they are as much as ten feet in length.

Frequently a portion of the ridge forms a conical hill such as is seen at Taylorville station.

Similar ridges of drift occur at many points along the Susquehanna; always in the centre of the Wyoming valley, and parallel to the motion of the ice as it moved south-west.

That the ridges just described are very different from terraces is evident; and that they are due to a different cause is very probable from the facts just enumerated. They appear indeed to be true *kames*, similar in all respects to those already described in more eastern counties.

The drift ridges which occur on high ground are frequently of a different character. They are often composed of unstratified till, and hold many striated pebbles and large erratics. They resemble the terminal moraine, and are *moraines of recession*, such as Prof. Cook has noticed in New Jersey. They represent halting-places in the retreat of the glacier. Deposits of this character may be seen at Lehigh Summit, and at other points upon the Pocono plateau along the line of the Del., Lack. & West. R. R. Similar deposits occur upon the Nescopeck mountain upon the line of the Lehigh Valley R. R. and are exposed in railroad cuts between Fairview and White Haven.

Mention should also be made of the small *lakes*, more than 30 in number, and of the many *peat-bogs* which owe their origin to glacial agencies. In many cases they are surrounded by heaps of drift which have obstructed their outlets. Sometimes they are true kettle-holes, in kame-like ridges of stratified material. Frequently a stream is dammed

up by a ridge of drift so that either a lake or a bog is produced.

Of the peat-bogs one of the most interesting has recently been exposed in Scranton, where the alteration of a portion of the peat has produced a black homogeneous elastic jelly* hardened into a coal-like substance, illustrating the first step in the formation of coal.†

*For this and similar substances the writer has proposed (Proc. Am. Phil. Soc., 1881) the name *Phytocollite*.

† [I have just received information from Messrs. Jones, Simpson & Co. that a *glacial pot-hole choked with gravel*, oval in horizontal section, 20 feet in diameter, and 40 feet deep from the surface, has been encountered in their colliery at Archbald. The sand and gravel having been removed it is now a perfect air-shaft, clean cut through the rocks which overlie the coal bed. The bottom part of the pot descends nearly to the floor of the coal bed. The coal all around it was in perfect condition. Some of the gravel stones weighed over 5 pounds. Much of the mass was fine sand. The rock walls of the hole are smooth, and a ridge or flange rises spirally from the lower part towards the surface, showing that the process of boring the hole was not carried on with rapidity and regularity, but slowly and irregularly; the stream above keeping the stones in the hole revolving and grinding deeper and deeper.

Such pot-holes are numerous in all glaciated regions, and very fine examples have been left at Lucerne, in Switzerland, by the retreat of the glacier which once occupied the Lake of the Four Cantons.

Good examples have been exposed by canal cuts at Cohoes Falls, near Albany, N. Y., in one of which bones of the Mammoth were found mixed with the gravel.

Glacial water-falls are supposed to have some effect in commencing or completing such pot-holes, because existing cascades leave such behind them in beds of streams as they recede up stream. The deep, symmetrical pot-holes in front of the Falls of Caughnawaugha creek, east of Little Falls, N. Y., are instances.

An "Observer" has communicated to the *Scranton Republican* a mention of a pot-hole, near Winton & Dolph's mines, two miles from Jones, Simpson & Co.'s mine, one and a quarter miles from Archbald, at the upper falls of the South branch of Middle creek, or Laurel run.—J. P. L. Feb. 25, 1884.]

CHAPTER VIII.

In Columbia County.

Berwick is built upon a plain of stratified drift, which extends a mile back from the river, at an elevation of 50 feet above it (550' A. T.) It forms a level-topped bluff or terrace of that height on the river bank, and while it diminishes in height below Berwick, becomes gradually higher above the town, until it meets the moraine two miles above in Luzerne county. (See Fig. 3, page-plate 14, page 102.)

The plain of stratified drift is not perfectly level, but shows shallow depressions or furrows, running in the direction of its length, parallel to the river, evidently the result of water action. The deposit, as shown in the R. R. cuts, is water-worn and sandy, and has a confused though evident stratification. An excavation back of the town shows that its layers sometimes have a steep dip, indicating rapid water action. Its pebbles show no weathering and are often flat, while boulders are scarce.

The plain of drift is bounded on the north by hills of slate and sandstone, the soil of which is filled with sharp fragments of the decomposing rock. Occasional water-worn boulders lie upon these hills.

Course of the moraine in Briar Creek township.

The moraine enters Columbia county at about the centre of the north and south line of *Briar Creek township*. It

(113 Z.)

is tolerably well defined on the county line where it crosses a road leading north-east from Foundryville, about $1\frac{1}{2}$ miles from that village. Large boulders of conglomerate lie upon it here, and many striated pebbles occur; but although thus well marked it has no characteristic contour. The moraine trends somewhat south of west, keeping along the base of Lee's Mountain. It passes about $1\frac{1}{4}$ miles north of Foundryville, and is recognized by its boulders and striated fragments at each road that it crosses. A boulder of coarse conglomerate is buried in the ground on the road-side near the house of A. Lockard, the exposed portion of the boulder measuring 10×10 feet. It passes just above the Methodist grave-yard, north-west of Foundryville; crosses a small creek at the cross-roads a mile farther west; and thence passes westward into Centre township just above the road which runs nearest to the mountains.

Throughout its course in Briar Creek township the moraine can be recognized by the occurrence of boulders and striated pebbles, but not by any special topography of its own. No ridges of drift, no kettle-holes or stratified kames appear, and the till is thin, and boulders scarce. North of the moraine, moreover, and from there to the mountain back of it, the rocks are so bare, and the covering of till or boulders so infrequent and fragmentary, that when exploring the region the first time the writer was frequently in doubt whether he was in front or back of the moraine. This perplexity was increased by the fact that in this township boulders frequently occur in front of the moraine at considerable elevations. It was often only by close examination of the boulders themselves that the point could be decided; those behind being often striated, while those in front were almost always smooth and water-worn.

Striated boulders have proved to be the best test of a glaciated region. It requires some practice however to recognize striated boulders. They are best seen, when lying on the roadside, either on a sunny day when the shadows of the *striae* are distinct, or when wet during a rain. They can sometimes be recognized by the feel, though this is never

certain. It is often necessary to hold them in a slanting light that the striæ may be seen.

Boulders six or more feet in diameter indicate the line of the moraine.

Its feeble development here illustrates the general rule that in front of a mountain the moraine is small and the ground uncovered by till. I invariably found upon the northern side of such a mountain large accumulations of drift material such as would have formed the moraine. Only such boulders as were carried over the mountain by the top ice were dropped where a terminal moraine would otherwise have been accumulated.

An instructive portion of the moraine occurs at a point $3\frac{1}{2}$ miles N. W. of Berwick where the moraine seems to abut against a high slate hill. The moraine, characterized by large boulders and by striated pebbles, comes to an end at the base of the hill, while sharp fragments of Pocono sandstone (brought from the north) continue up nearly to the top of the hill. Here then we have as it were a *vertical section* of the glacier, showing that it bore small sharp fragments on *top*, such fragments being identical with the frost-broken fragments which are now falling down the slopes of Lee's Mountain. It seems that we have here a measure of the thickness of the glacier at its extreme edge—a *thickness not exceeding 400 feet*. Moreover, in the fragments of Pocono sandstone we have evidence that ledges of rock on top of the mountain may have risen above or close to the surface of the glacier as it passed over the mountain.

Course of the moraine in Centre township.

In Centre township the moraine runs south of west along the base of Lee's Mountain, being easily recognized on the upper road to Orangeville. There is a sudden transition from the soil made up of broken shale, upon which no boulders are seen, to that made of an impure yellow clay filled with boulders and striated fragments. Near the Orange township line, on the upper road to Orangeville, and at the farm of W. Beck, the fields are completely covered by boulders, many of which are over four feet in length.

Sharp fragments of Pocono sandstone also occur in great abundance.

At this point the moraine comes to an end and appears to turn back on its course in ascending the mountain; but on account of the heavy woods it was impossible to trace it.

All that can be said with confidence about it is, that it crosses the combined Lee's and Huntington mountain and gets over into the Fishing Creek country beyond. It certainly ascends the south slope of Lee's mountain, crosses the narrow elevated red shale valley between the crest of Lee's and the crest of Huntington mountain, and slants westward down the north slope of Huntington mountain.

The two crests of Lee's and Huntington mountains diverge eastward towards Shickshinny; but converge westward, to make Knob mountain.

The road from Berwick over to Jonestown and Asbury crosses the double mountain where its two crests are only about 1000 yards apart, and the red shale valley is but a gentle depression between them (about 350'). This is 3 miles west of the county line.

The following facts must now be considered:

1. Ascending Lee's mountain by this road from Berwick, glacial striæ are seen bearing S. W. This shows that the ice moved down the south slope of Lee's mountain diagonally *westward*. Of course the terminal (just here a *lateral*) moraine must be looked for on the slope west of the road. But it has already been said that in Centre township the moraine is easily recognized on the upper road from Berwick to Orangeville, near the Orange township line, which is six miles further west than the road across the mountain with its S. W. scratches.

2. The *crest* of Lee's mountain, where the road crosses it, is striated and bears striated pebbles.

3. Hills of drift having the aspect of a terminal moraine occupy the red shale valley between the two roads which cross the mountain—one at the county line—the other (above referred to) two miles west of it.

These two roads pass through two notches in the crest of

Lee's mountain; but they go over the unbroken crest of Huntington mountain. The moraine ridges are between the two notches, and seem to mark the western extension of the ice up the red shale valley. At the eastern road, on the county line, the red shale valley is piled full of both angular and rounded boulders, and heaps of them occupy the valley all the way down to the Susquehanna river at Shickshinny.

The crest of Lee's mountain runs along at an elevation of about 1500' A. T.

The eastern notch is cut down about 225 feet below the crest, to 1275' A. T.

The western notch is cut down about 270 feet below the crest, to 1230' A. T.

The melting ice waters probably issued by the notches southward; for there are no notches in the crest of Huntington mountain, which is 1500' A. T. where it is crossed by each road, and a little higher in other places along the crest.

The fall of the Little Shickshinny creek (in the red shale valley) eastward, in the two miles between the two roads, is 1140'—1030' A. T.=110 feet.

The water in the red shale valley at the western road is only 1230'—1140'=90' lower than the Lee's mountain western notch; while it is 1500'—1140'=360' lower than the Huntington mountain crest. Two miles further east, the water in the red shale valley is 1275'—1030'=245' lower than the eastern notch; and 1500'—1030'=470' lower than the Huntington mountain crest.*

4. No drift appears upon the crest of Huntington mountain, at the western road (from Berwick to Jonestown); but where the eastern road crosses it in Salem township, Luzerne county, there is an abundance of moraine matter on the crest of the mountain, just as there is in the red shale valley.

It is evident that the sea of ice which filled the Fishing Creek country to the north, and the Berwick country to the south was split by the double-crested Lee and Huntington

* See Report G⁷, p. 275.

mountain; and that the terminal moraine, which is so plainly exhibited slanting westward down the north slope of Huntingdon mountain towards Asbury, should be looked for along a line similarly slanting westward down the south slope of Lee's mountain towards Orangeville.

5. The Berwick-Jonestown road descending the north slope of Huntington mountain encounters the moraine lying along the mountain side. It is finely developed near Jonestown and Asbury; but nothing is seen of it further west, because it turns and runs north.

Several features of interest must now be described.

On the road leading across the mountain from Berwick to Benton, after leaving the plain of stratified drift at Berwick, and after crossing the moraine $1\frac{1}{2}$ mile N. W. of Foundryville, and the region back of it sparsely covered by till, the mountain is ascended and indistinct glacial striæ noticed on a steeply inclined surface of Catskill sandstone. These bear in a S. W. direction, and are at an elevation of 1150 feet above the sea. Very occasional transported pebbles occur on the south side of the mountain. In the shallow valley on top of the mountain is a low ridge of transported and striated pebbles and boulders, which appears to be the moraine again. On the northern portion of the mountain, which rises 400 feet above this point and 1550 feet above the sea, no drift is seen until, after descending the northern slope to a point 300 feet below the summit, a few rounded pebbles begin to appear. Approaching the base of the mountain fine knob-like hills of drift, long, narrow, kame-like ridges, numerous large and striated boulders, and a deep covering of till, show that the moraine, finely developed, is hugging the northern slope of the mountain. (Spec. of boulder No. —.) This is about $\frac{2}{3}$ of a mile before reaching Jonestown; and the road follows upon it as far as Asbury. Fine rounded hills of drift occur upon Huntington creek near Jonestown. A kettle-hole occurs close to the village. A beautiful and typical kame runs from Jonestown a short distance down Huntington creek and the locality exhibits most of the phenomena already described in Cherry valley, Monroe county.

Glacial striæ occur $\frac{1}{4}$ mile N. of Jonestown.

In its course across the wide valley between Huntington mountain and the Allegheny mountain the moraine can be traced with great precision. At each of the numerous roads which cross it, at distances less than a mile apart, its position has been mapped, and in many places it has been traced continuously.

Course of the moraine northward.

A quarter mile W. of Asbury it turns northward toward Benton. It keeps on the east side of Fishing Creek as far as Cole's Mills, where, in crossing it, the moraine forms a great ridge extending obliquely across the valley of the creek. It then passes across Jackson township in a northwest direction to the corner made by Lycoming and Sullivan counties. Throughout the whole of this course the moraine is wonderfully well shown and has characteristic topography.

On the southern edge of the moraine, upon the road from Jonestown to Cambria, striæ occur upon Marcellus shale, just north of the Methodist church, and close to the junction of the Marcellus shale (VIII) and Catskill sandstone (IX), and bear S. 32° W.

The moraine leaves the base of the mountain at a school-house 1 m. S. S. E. of Asbury at the meeting of roads from Asbury and Jonestown. It here forms a distinct ridge stretching diagonally across the valley of Huntington creek.

Here deep masses of stratified drift rest against the western edge of the moraine and continue down the valley of the creek, becoming more shallow the farther it is from the moraine. Near the moraine this plain of stratified drift, composed of water-worn pebbles (and at least 30 feet in depth as shown by a terrace cut in it by the creek) has its surface moulded into shallow ridges and depressions, all of which are parallel to the creek and evidently made by water action. These ridges are at right angles to the moraine and clearly show by their topography alone the distinction between the action of ice and of water.

The moraine now trends to a point $\frac{1}{3}$ of a mile W. of

Asbury, where its edge is very sharply defined upon the road by the sudden change in the color of the soil. The yellow till gives place to a red soil formed by the decomposition of Catskill shales. No boulders whatever occur west of the moraine, the ground from here to Fishing creek being perfectly free from drift.

Above Asbury the moraine turns somewhat east of north passing not quite 2 miles W. of Bendertown, as high drift hills covered by large boulders, and sharply defined on its edge. On the next road north of Asbury its limit is well marked near the forks of road about $\frac{1}{2}$ m. E. of Fishing creek. It is well seen on the road running north and south from W. Traxler's to J. McMichael's. Its edge is sharply defined at the cross road near Mr. Hess's house.

One and a quarter miles E. of Stillwater it forms distinct rounded hills and is easily recognized on the road from Stillwater to Bendertown. The farm of Alden is upon the moraine. It crosses Raven's creek less than two miles N. of Stillwater and $\frac{1}{2}$ mile above the point where the road crosses the creek. Close to this point the moraine crosses the line between the townships of Benton and Fishing Creek.

It is a curious fact, that although the moraine from Asbury to this point runs so near Fishing creek, no drift whatever, stratified or unstratified, occurs in the valley of that creek. The slates and shales of VIII are exposed on both banks of the creek; and the sandy alluvium forming the fertile bottom land is perfectly local. The edge of the glacier must have been drained backwards. A careful examination showed that along the whole course of the moraine east of Fishing creek *no drift whatever occurs west of the moraine*. Nowhere is the distinction between a glaciated and a non-glaciated region more sharp.*

THE TERMINAL MORaine CROSSING FISHING CREEK VALLEY, COLUMBIA COUNTY, PA. LOOKING S. W. (PICTURE REVERSED.)

AMOTHS, E. HENSTADT, N. Y.



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Course of the moraine in Benton township.

The moraine enters Benton township near the point where Raven's creek crosses the township line, and then approaches within a mile of Fishing creek. It forms drift hills, covered by boulders of sandstone and conglomerate brought from the Allegheny mountain. Approaching Fishing creek still more closely, and bending somewhat east of north, the moraine passes along the western side of a hill which slopes toward the creek, a mile below Benton; and from thence to the top of a high hill which forms the bank of the creek east of Benton. As in Fishing Creek township, the moraine has been drained backwards into some of the valleys farther east; these back valleys are in fact now filled by drift accumulations. Notwithstanding the close approach of the moraine to Fishing creek no drift whatever appears in the latter. A thorough exploration showed that while the hills forming the east bank of this creek are covered by drift so deeply as often to conceal all rock outcrops, *the hills on the west side of the creek are perfectly bare*, and show not a trace of drift. The village of Benton for example lies in the middle of the prosperous and fertile valley (half a mile or more in width) which follows Fishing creek most of its course.

On ascending the hills (350 feet high) *east* of the valley a region is entered which is completely covered by till, transported boulders and striated fragments thrown up into irregular heaps and ridges.

If on the other hand the hills of similar height *west* of Benton be ascended not a single scratched or transported pebble or any sign of glaciation is seen.

The glacier terminated abruptly on the eastern side of the creek.

This fact cannot be explained by any change in elevation or in topography, since the hills on both sides of the creek rise about 350 feet above it.

A mile below Benton the moraine ends abruptly on the edge of a hill descending towards the creek, a fact at variance with any other hypothesis than that of a glacier as the cause of the moraine. The presence of *striæ* and of trans-

ported boulders upon the summit of the Allegheny mountain to the north precludes also the idea of local glaciers.

It seems probable therefore that the continental glacier stopped just where it did simply because the inertia or moving force of the glacier, from whatever cause derived, became exhausted at this point. Increased temperature was the only barrier.

Returning once again to the course of the moraine in Benton township, it is found that the moraine descends into the valley of Fishing creek at Cole's mills, two miles north of Benton, where it forms a great ridge of drift over two miles wide, stretching across the valley from side to side. The moraine fills the bottom of the valley and appears on both sides of the creek. The road going north from Cole's Mills (Waterville) on the east side of the creek ascends the moraine, and in several cuts gives good exposures of the unstratified till. About half a mile north of Cole's Mills the road ascends a moraine hill (some 75 feet in height) which is cut through by the creek. The numerous boulders of sandstone and conglomerate, often over 6 feet in length, and the rounded drift hills dumped near the creek, give the valley a very different appearance from what it has at Benton and below.

In Sugar Loaf township.

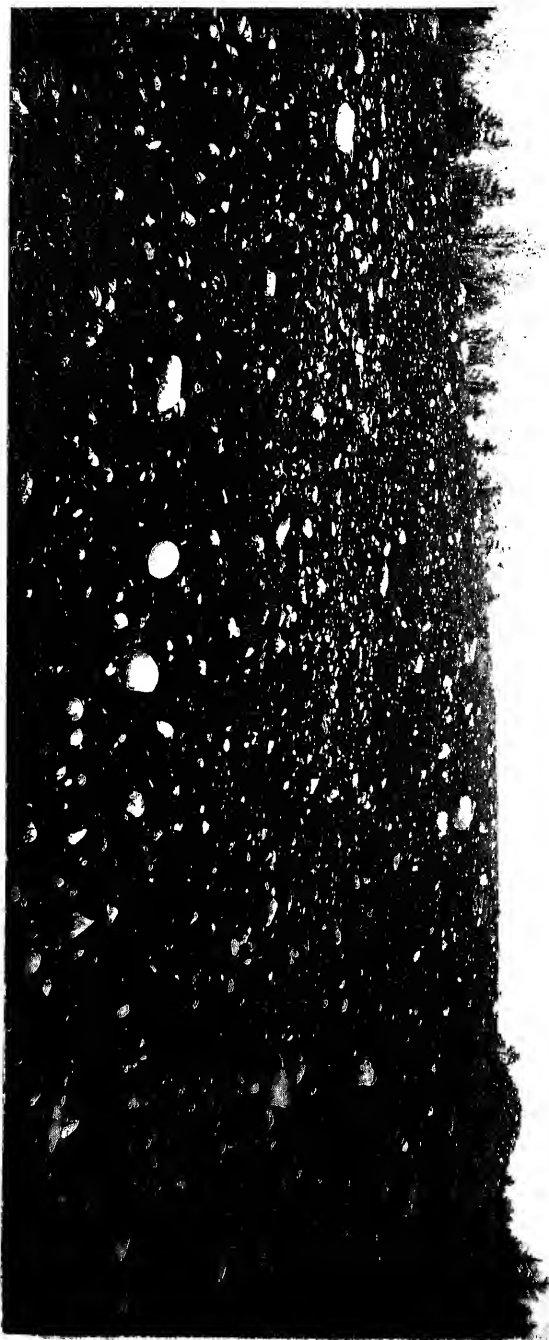
At Cole's Creek P. O., in Sugar Loaf township, the creek forks into Cole's creek and Fishing creek. The moraine here forms fine conical hills in the centre of the valley.

At the bridge near E. Cole's, north of this, the glaciated region back of the moraine is reached, and a fine view can be obtained of the *back* of the moraine, which appears steeper, more regular and better defined than the front; an important fact noticed at other points in the State. Beautifully rounded hills of drift rise like cumulus clouds one back of the other. (See plate on page 92.)

The moraine, stretching conspicuously across the valley from Cole's Creek to Fishing Creek, and ending abruptly near the bridge, can be seen for a mile or more from up the

THE TERMINAL MORaine, WEST OF COLE'S CREEK, ON COLUMBIA COUNTY. (PICTURE REVERSED.)

AMSTER, E. HENNINGSTADT, N. Y.



creek. Hence to the base of the Allegheny mountain the valley is nearly flat and contains no drift hills.

Having crossed Fishing creek the moraine continues in a north-west direction across the south-west corner of Sugar Loaf township, passing near a school-house on a creek about two miles N. E. of Polkville P. O. In some places the boulders (many of white conglomerate) are so large and numerous as to render the soil unfit for cultivation.

In Jackson township.

In Jackson township as the moraine approaches the base of the Allegheny mountains (here known as Bald Mountain) it is less finely developed. It crosses the upper part of the township near the base of the mountain. The till here is very thin and often absent east of the moraine ; but the occasional striated boulders prove the region to have been glaciated. As noticed in similar circumstances before, the moraine approaches the mountain on a course nearly at right angles to it, and when close in front of the mountain is poorly developed.

Back of the moraine, in the gorge made by Fishing Creek with the Allegheny mountain (North mountain) on the road to Laporte, about $\frac{1}{4}$ mile above the road forking to New Philadelphia, is a ridge or accumulation of till and boulders (many of which are striated) and which rises nearly 100 feet above the stream. It is perhaps a *moraine of recession* or a *mountain moraine* such as those seen in Monroe county.

As already stated no drift occurs in front of the moraine except in the vicinity of streams. In the valleys of Green, Little Fishing and other creeks running southward there occur boulders and sharp fragments of Pocono sandstone and boulders of Pottsville conglomerate. They are often over three feet long, and were probably brought by floating ice. Although they often lie on high ground, such ground is always near a depression down which a great flood of water might have come.

Near Orangeville, where Huntington and Fishing creeks join, there is a plain of stratified river gravel nearly a mile

in width. It forms a terrace 20 feet high at Orangeville and is composed of smoothed (often flattened) pebbles overlaid by sand. It was evidently deposited by a glacial stream which flowed along the valley of Huntington Creek.

In Sullivan county.

The moraine probably just touches the lower corner of Sullivan county. It at least approaches it so closely as to make it necessary to give the proof of the glaciation of that county. The observations of the writer have been confined to Davidson township, the most southern township of the county.

The Allegheny (North) mountain (2000 feet A. T.) forms the southern part of the township, rising precipitously from the broad undulating low country of Columbia county on the south. North of the mountain is the valley of Muncy creek.

Upon the high (Pocono SS.) plateau of the mountain transported boulders are scarce. Sharp fragments of frost-broken Pocono sandstone cover the surface; and no till appears; striæ were seen near the highest part of the mountain (at an elevation of about 2000 feet above the sea) at least 1000 feet above the moraine lying at the base of the mountain some five miles to the south. The striæ are on Pocono sandstone near the head-waters of Painter's run and bear S. 9° W.

The observation is of interest for several reasons:—

- (1) It shows the moraine at the base of the mountain to be that of a continental, not a local glacier;
- (2) It proves the great thickness of the glacier close to its edge;—and
- (3) It proves the motion of the ice to have been at right angles to the terminal moraine.

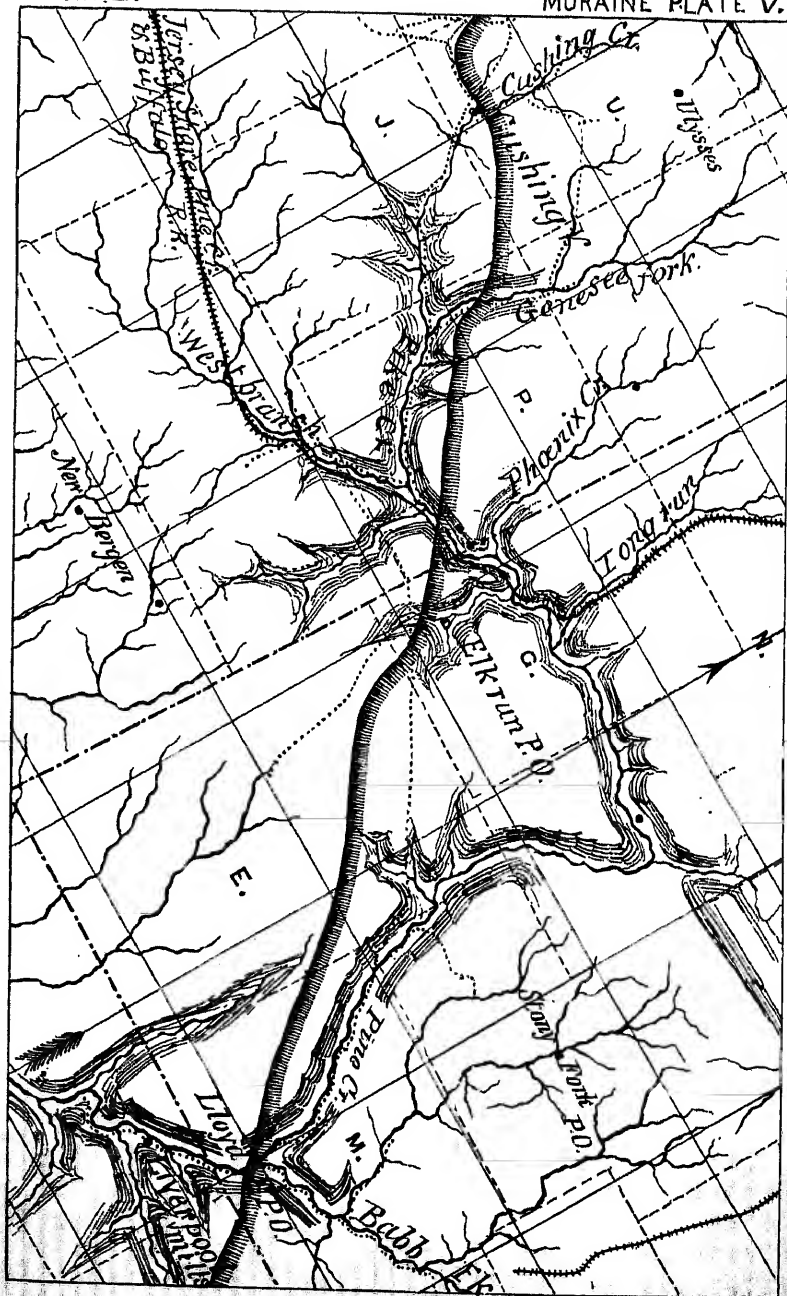
Striæ also occur a half mile farther north on the same road across the mountain somewhat north of the summit. (These are on an inclined surface of rock and their true direction was not taken. One of the grooves is about an inch broad.) Boulders and striated pebbles occur more

frequently on the northern slope of the mountain. Till is nearly absent both upon the mountain and in the valley of Muncy creek to the north.

This absence of till and scarcity of boulders on elevated points shows the comparatively pure character of the upper portions of the glacier. The till was evidently transported by the bottom of the ice.

Striæ occur in the valley close to Muncy creek, 2 miles W. of Davidson on the road from Davidson to Sonestown. They are grooves in Catskill sandstone, and are seen on both sides of the road. They run *up hill* S. 80° W.

These are perhaps 750 feet lower than those noticed upon the mountain, and their direction has evidently been influenced by the valley down which they run, the course of which is approximately that of the striæ.



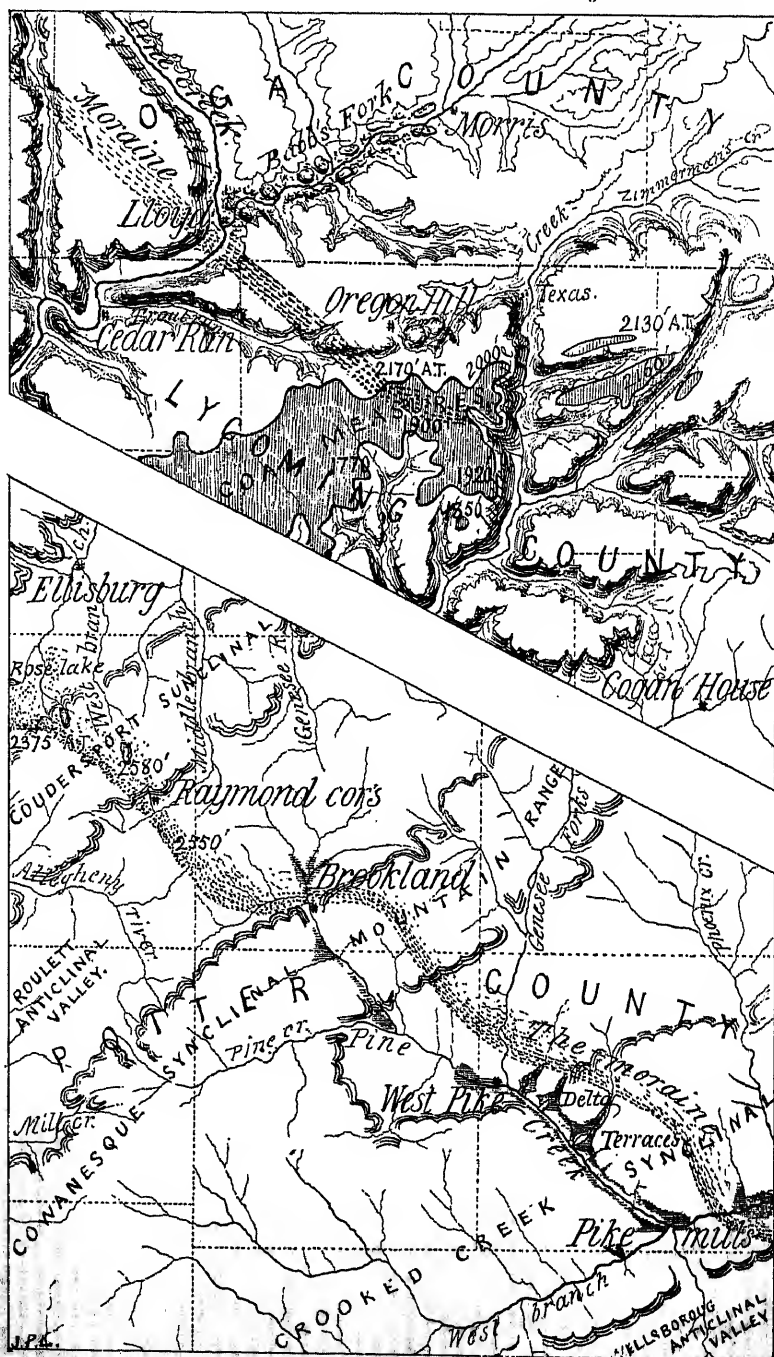
CHAPTER IX.

In Lycoming county.

The wild scenery which characterizes the region north of the escarpment of the Allegheny Mountain, the picturesque cañons of the Loyalsock, Lycoming, Pine and other creeks, and the almost unbroken wilderness of northern Lycoming county, while rendering the exploration of the moraine a matter of some difficulty, add interest to a description of its course, and must stimulate to farther observations. Visitors to Ralston could find no more delightful occupation than to give point to their mountain rambles by augmenting and making more exact the scanty data of the glacial phenomena of Lycoming county here presented.

The moraine enters Lycoming county in *Jordan township* near the corner made by Columbia and Sullivan counties. It passes along the base of the Allegheny mountain but is poorly defined. On the high hills near Unityville, which appear to be south of the moraine, boulders of Pocono sandstone 2 to 3 feet in length are of frequent occurrence. On Little Muncy creek, north of the village, are deposits resembling till, except in the scarcity of scratched boulders. Along the foot of the mountain sharp pieces of Pocono sandstone cover the ground.

In *Franklin township* the moraine is more clearly seen. It is distinctly marked where it crosses Beaver Dam run and Little Marsh run, 2 miles north-east of Lairdsville. It





is distinctly marked as a drift hill in the valley close to the creek. The road from Lairdsville up Beaver Dam run ascends the moraine just above the road fork at Little Marsh run, and exposes the unmodified till in a cut on the roadside. Till continues north of the moraine on Little Marsh run, up to the Allegheny (North) mountain, at the base of which are fine moraine hills larger than those of the true terminal moraine.

Continuing westward the moraine appears to cross Big run near a saw-mill, $1\frac{1}{2}$ miles N. of Lairdsville, close to the line of Penn and Franklin townships.

In *Penn township* the moraine is indistinct, and the region immediately north of it remarkably free from drift of any kind. Three miles north-west of Lairdsville the moraine appears to cross a high hill, at a cross road, where it is known simply by the presence of white boulders of Pocono sandstone and Pottsville conglomerate which, lying on the red Catskill soil, are conspicuous objects. Till is nearly absent here, though abundant in the valley of Big run half a mile farther east. Passing to a point about 3 miles N. E. of Hughesville it trends just north of Zion Hill church to Muncy creek, which it crosses between Picture Rocks and Tivoli. The moraine is well characterized north of Zion Hill church, where it is nearly a mile in width.

Immediately north of the moraine there is a remarkable scarcity of boulders and till, as though either the glacier had retreated very quickly for several miles after beginning to recede from its terminal moraine; or else, as though the ice was so free from transported material as to leave but scanty marks of its passage. The latter explanation is supported by the fact that the Allegheny mountain lies immediately to the north, across which only the upper and purer portions of the ice would flow.

Several occurrences of *glacial striæ* were noticed in the northern part of Penn township, all upon Catskill red shale.

Near the house of Mr. Crawley they bear S. 9° W. On the same road farther south, and near the house of C. McCarty, somewhat over a mile from the Sullivan county line, they bear S. 17° W. Still closer to his house and farther

south they bear S. 22° W. these last being at a lower elevation than the first.

In *Shrewsbury township* the moraine crosses the lower corner, and forms an accumulation of till, large boulders and scratched stones on the line between Shrewsbury and Wolf townships, 400 feet above the valley of the creek.

The southern wall of the Allegheny mountain is here but two miles to the north, rising more than 2000 feet above tide. The moraine passes westward along its base in the upper portions of Wolf, Muncy and Upper Fairfield townships, until, after crossing the Loyalsock creek near the village of Loyalsock, it turns (nearly at a right angle) to the north and ascends the mountain in Eldred and Lewis townships.

Where it crosses the Loyalsock creek the moraine has been modified by water action, and is represented by a plain of water-worn boulders and pebbles, about $\frac{1}{2}$ mile north of Loyalsock P. O. In the lower part of the village on the east side of the creek is a hill of water-worn drift probably derived from the moraine.

In *Eldred township*, the moraine may be seen on the road from Warrentown to Loyalsock, running along the base of the mountain about half a mile distant. It crosses Mill creek one mile N. W. of Warrentown, and is distinctly seen two miles N. W. of Warrentown as it turns toward the mountain.

In *Lewis township* it trends northward to a point one mile east of Rose Valley P. O. where, at an elevation of probably 1400 A. T., it is finely shown by characteristic low knob-like hills with abundance of boulders of Pocono sandstone, Pottsville conglomerate, Carboniferous sandstone, etc., many of which are striated—the whole contrasting sharply with the red Catskill soil in front. A swamp (once a lake) occurs at Rose valley and is of glacial origin. It seems that its waters once flowed eastward into Murray's run; but that when the moraine was heaped up at its outlet a lake was formed whose waters then forced a channel for exit at its western end through the soft red shale.

A large boulder of Pottsville conglomerate (measuring

when exposed 15×25 feet) lies as an *outlier* nearly half a mile in advance of the moraine hills, partially imbedded in the red Catskill soil of a field on the farm of J. Hall.

No trace of drift occurs west of this point ; while the region to the east shows every sign of glaciation.

From Rose Valley the moraine passes first northward, to cross Shoemaker run about a mile from where it empties into Lycoming creek ; and then east of north into the north-western corner of Cascade township.

It is finely developed on Shoemaker run as a belt of rounded drift hills nearly a mile in width, at the extreme western edge of which occur several large boulders, all over six feet in diameter.

The moraine is readily seen from the road leading from Rose Valley northward towards Kellysburg. (Specimen of striated pebble No. —.)

It is here bearing nearly north ; and, as a consequence, the glacial striæ near Rose Valley bear more westwardly than usual, viz: S. 76° W.

They may be seen on the road just mentioned $\frac{1}{2}$ mile N. E. of the cross road leading down Shoemaker's run, and two miles N. E. of Rose Valley P. O. They are on Catskill sandstone.

In *Cascade township* the moraine appears at the house of Mrs. McGee on Slack's run where a drift hill, covered by boulders of Pocono, Pottsville, Chemung and Catskill rocks, extends across the valley and rests against the mountain (Burnett's ridge) to the north.

The precise point where the moraine crosses Lycoming creek cannot be fixed with certainty. The floods which sweep down the narrow gorge in which the creek flows have completely obliterated it from the centre of the valley. Traces of it however remain in sheltered places at the sides of the valley.

Nor has it been possible to get definite data upon the mountains west of the creek, which, for a distance of fifteen miles, are densely wooded and not accessible by a single road.

The moraine probably crosses Lycoming creek between

Bodinesville, and Ralston, near the common line between McIntyre and Lewis townships. Nearly opposite the mouth of Pleasant Stream, on the west side of Lycoming creek, occur accumulations of drift containing numerous boulders and very occasional striated fragments, which probably represent the moraine. Two miles below this point, at Bodinesville is a long ridge of stratified water-worn drift (seen prominently from the railroad station) indicating the near proximity of the moraine. No signs of glaciation were discovered upon the high ground west of this point.

North of Ralston the mountains on both sides of the creek show plain signs of glaciation.

At McIntyre, a mining village 2200 A. T., glaciated till covers the mountain to a depth in several places of 30 feet, while numerous transported and striated pebbles and sometimes rounded hills of till are found. In the valley of Lycoming creek, a thousand feet below, glacial striæ occur at the mouth of Abbot's run, one mile north of McIntyre station. A nearly vertical exposure shows striæ bearing S. 5° E. to S. 25° E. following the direction of the gap, but of course deflected by the nearly vertical wall of rock. Glacial till occurs in the ravine of the same tributary creek.

West of Ralston, on the mountain, probably a thousand feet above Lycoming creek, striæ were discovered upon carboniferous sandstone bearing about S. 35° W. These may be regarded as representing the general movement of the ice across this region. Till was not observed upon this densely wooded mountain.

The moraine now traverses the south-western portion of *McIntyre township*, and is next observed in *Jackson township* upon the very summit of Laurel Hill, 2300 A. T.

Here 2 miles S. E. of Buttonwood P. O. it forms low rounded hills covered by boulders, and is crossed by the road leading across the mountain from Block House to Trout run. On the same road, half a mile north of the moraine, and at an elevation of about 2115 A. T. striæ occur upon Pocono sandstone bearing S. 34° W. These are on the northern slope of the mountain near the summit.

The moraine probably crosses the deep ravine occupied

by *Block House run* about one mile south of Buttonwood P. O. where a ridge of stratified drift stretches across the valley. Boulders and pebbles continue for a short distance below, in the valley of the creek, but are absent upon the high ground.

In *Cogan township* no trace of glaciation was anywhere found.

The next place to the west where the moraine is finely shown is in *Pine township* $1\frac{1}{4}$ miles south of Oregon Hill P. O. It here occurs with characteristic knob-like hills holding kettle-holes and swamps upon the very summit of the mountain, about 1900 feet above the sea. Striated boulders are very numerous, and boulders of greatly varied lithological composition cover the fields. The road leading from Oregon Hill P. O. southward over the mountain crosses the moraine at Hemenway's.

A deep mantle of till, with numerous erratics and scratched boulders, covers the region lying north of the moraine in Pine township.

The deep and wild ravine of Little Pine Creek has retained no trace of the moraine; but at Texas, at the head of the ravine, glaciation is undoubted. Striated boulders are numerous, and upon the hill west of the village glacial striæ occur upon Catskill sandstone. They bear W. S. W. but are too imperfectly preserved to admit of exact measurement.

The moraine appears to leave Lycoming county in the N. W. corner of Pine township and to cross Pine creek in Tioga county.

The signs of glaciation *north of the moraine* are undoubted. Glacial striæ abound in Jackson township. In addition to those described near the summit of Laurel Hill I have noted:—(1) In the N. E. corner of the township, near an old saw-mill upon Roaring branch, striæ occur upon the roadside bearing S. $52^{\circ} 30'$ E. (W.?)—(2) A quarter of a mile N. W. of the bridge, higher up the hill, they bear S. 66° W.—(3) On top of the hill $\frac{1}{4}$ mile beyond the house of J. Kehler, on the same road, they bear S. 53° W.—(4) Two miles N. E. of Buttonwood P. O. upon a road going E. and W. parallel with the mountain, and at an elevation

of about 1765 A. T. striæ occur bearing S. 64° W.—(5) Upon the road leading from Block House over the mountain to Trout Run, $1\frac{1}{2}$ m. N. E. of Buttonwood P. O. and near the base of the mountain, several exposed surfaces of rock showing striæ occur. The average direction of these is S. 55° W. and their elevation about 1800 feet A. T.—(6) Upon the road from Block House to Buttonwood P. O. (Seacrist mills) somewhat more than a mile north of Buttonwood, an exposure on the E. side of the road is covered with striæ bearing S. 48° W.—(7) On the same road, $\frac{1}{4}$ m. N. of Buttonwood P. O. indistinct striæ run up an embossed surface of rock, the best of which bear about S. 30° W.—(8) Still closer to the house representing the town they bear S. 28° W.

All of the above striæ are in the valley north of Laurel Hill, and all are upon Catskill sandstone.

The true motion of the *upper ice* is shown upon the mountain (both here and back of Ralston) to be S. 34° W. or S. 35° W. In the valley the bottom of the ice was deflected westward, along the valley, so as to flow more nearly parallel with the mountain. Most of the striæ observed were upon hills in the main valley.

Nearing the moraine the striæ turn so as to be more nearly at right angles to it.

The fact seems to be established that striæ are most numerous on the north side of a mountain and especially in valleys north of a mountain.

The region *south* of glacial action in Lycoming county exhibits several features of unusual interest. While *deposits of stratified drift* will be more fully treated in another report, they are so clearly connected with the moraine that it will be proper to mention some of their most characteristic features in this place.

The West Branch of the Susquehanna river is in no place crossed by the moraine, and is therefore comparatively free from deposits of *stratified drift*. The moraine approaches the river most closely between Williamsport and Muncy, where it is but 6 or 7 miles distant. Capping several of the hills bordering the river between these points, in Muncy and Fairfield townships, there occur some unusual deposits

consisting of a loose sandy clay, less compact than till, holding, in addition to numerous sharp pieces of underlying rock, a large number of transported boulders and fragments, many of which show fine *striations*. These deposits lie upon hills rising 150 to 200 feet above the river but only in the vicinity of the river. Between them and the moraine is a hilly region perfectly free from drift.

These interesting deposits can probably best be accounted for by assuming that icebergs, derived from the glacier and carrying striated boulders, have been floated at that elevation and grounded upon the hills in question. Deposits of *brick-clay* at Williamsport, Hughesville and other points indicate some such event.

Among *deposits of later age* some of the most interesting are those upon Lycoming creek. These are composed of a sandy, partially stratified gravel, and were formed at the time of the final retreat of the glacier. A rounded pebble of *red granite* (Spec. No. —), evidently derived from the moraine, was found near the mouth of Lycoming creek.

At the entrance of each tributary stream into Lycoming creek between Trout run and the moraine, a prominent ridge of sandy gravel, not unlike a *kame* in contour, may be seen stretching down the valley from the point of confluence of the two streams. Two of the most conspicuous of these ridges occur at Bodinesville, and at the mouth of Gray's run. Each of them is about a mile in length, starting in a ravine and running down the side of the main valley. Unlike a *kame*, a cross-section shows a confused stratification and no anticlinal structure. Nor does such a ridge occur (like a *kame*) in the centre of the valley. It lies only at the junction of confluent streams, where an *eddy* in the waters or the shelter of projecting rocks allowed it to be formed. It has the appearance of having been formed suddenly, and of having been *washed into shape*. Such an *eddy-ridge* or, as it might be termed, *terrace delta*, only occurs near the glaciated region, or where the floods were heavily loaded with drift.

Special search was made among the high mountains of north-western Lycoming county for any traces of *local*

glaciers. No trace whatever of such glaciers was discovered, although the region is favorable for their formation; for the mountains rise to a height of over 2200' A. T. and are intersected by gorges more than 1000 feet in depth.

The whole region is perfectly free from drift except such as has been brought down those streams which pass through the moraine.

The old Coudersport and Jersey Shore turnpike bounds the county on the west, and in Potter county crosses an elevation of 2150 A. T. perfectly free from drift; and this high plateau region of the State, traversed by the moraine, has doubtless been the prime cause of the northing which it makes in Lycoming county.

In Tioga county.

The moraine crosses the wildest part of Tioga county.

In Morris and Elk townships it passes through dense woods not crossed by a single road for 13 miles.

It appears near the junction of Babb's creek and Pine creek, in the south-western corner of Morris township, near Lloyd P. O. A quarter of a mile below the mouth of Babb's creek a hill covered with boulders, on the west side of Pine creek, rises 100 feet above the creek. No similar accumulations occur below this point, and the creek flows in a deep gorge between often nearly vertical cliffs of Catskill sandstone.

One half mile N. E. of this point, on Babb's creek, is a similar accumulation of drift and boulders (many of them striated) rising 150 feet above the creek. Farther up Babb's creek ridges of till and stratified gravel occur at frequent intervals, and transported boulders are numerous. A ridge, composed of stratified sand within, and covered on top by numerous and large striated boulders, occurs on Babb's creek one mile below Morris P. O. Till and boulders also cover continuously the high ground between Morris P. O. and the Lycoming county line to the south. Therefore there

is no doubt that the accumulation of drift near the junction of Babb's and Pine creek is a portion of the moraine.

The moraine was next seen in the N. W. corner of Elk township, 3 miles S. of Elk run (Marshfield) P. O. where it goes N. W. into Gaines township; then passing $\frac{1}{2}$ mile west of Marshfield it enters Potter county.

It is readily traced upon the three roads near Elk run. No characteristic moraine hills appear, but the till is thick, and filled with striated pebbles and boulders. These striated stones are far more numerous than in the till back of the moraine.

The moraine is here about 1750 feet A. T.

Glacial striæ are numerous in Tioga county. Only those observed by the writer in the vicinity of the moraine are here noted. They are as follows:

(1.) In Union township 2 m. N. W. of Roaring Branch P. O. on the roadside near the house of A. Halleck, are two exposures of striæ, upon Chemung shale, bearing S. 72° W. at about 1700 A. T.

(2.) In the same township a fine example of striæ and of *roches moutonnées* occurs on an exposure of Catskill shale, about $\frac{1}{4}$ mile S. E. of Ogdensburg, on the stage road to Roaring Branch. The striæ run S. 66° W. The exposed surface is about 20 feet long, and shows plainly the direction of the ice movement coming from the N. E. The elevation is about 1725 A. T.*

(3.) In Liberty township, on the road from Ogdensburg to Block House, striæ were noticed upon Catskill sandstone in three places. Four miles south-west of Ogdensburg they bear S. 73° W. This is a limited exposure, and the striæ are poorly preserved.

(4.) On the same road, $\frac{1}{2}$ m. W. of the last occurrence, near a cross road leading north to Blossburg and at an elevation of 1875 A. T., striæ bear S. 73° W.

(5.) A mile and a quarter farther south-west, near the house of M. Schaeffer striæ occur on both sides of the road and have an average direction of S. 80° W.

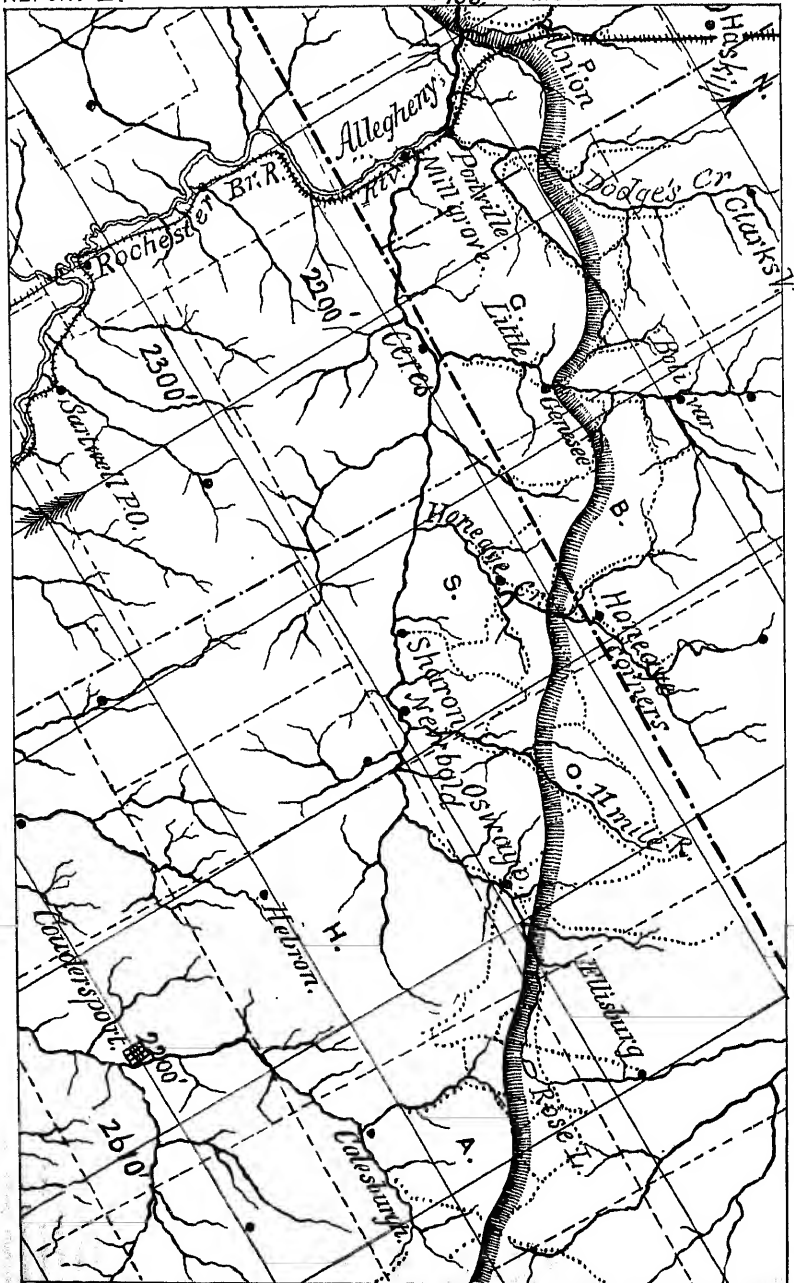
*In Report of Progress G, Mr. Sherwood notes this and several other localities of striæ on his map of Tioga county.

(6.) In Bloss township, close to the line of Liberty township, on the road from Blossburg to Block House, indistinct striæ upon Pocono sandstone, at about 1950 A. T. bear S. 57° W. These are grooves, and being upon sandstone are not well preserved.

(7.) Upon the same road, in Liberty township, less than a mile S. of the last striæ, and about $4\frac{1}{4}$ m. from Blossburg, is an exposure of Pocono sandstone showing *roches moutonnées*, and good striæ bearing S. 50° W. This is near the top of the mountain at an elevation of about 2060 A. T.

As usual the greater the elevation of the striæ the more nearly N. and S. do they run.

In addition to striæ Tioga county exhibits all the other phenomena of a glaciated region. The covering of till and boulders, in some places so deep as to cover all outcrops, in other places nearly or quite absent, the moraine-like ridges in the upper part of the county, the deep deposits of stratified drift in and near the streams, all attest the glaciation of the greater part of the county.



CHAPTER X.

In Potter county.

The course of the moraine across the high plateau region of Potter county is especially interesting because it attains its *maximum* elevation in the centre of the county. Its line, though undulating, is remarkably straight; and its elevation, except where crossing deep ravines, varies from about 2200 to nearly 2600 A. T.

In Allegheny township it reaches 2580 A. T., an elevation greater than it attains anywhere else in the United States.*

This is a continental summit from which divergent streams eventually flow into the Gulf of Mexico, Lake Ontario and Chesapeake Bay.

Here the moraine is well developed, and, where the region is open to travel, can be traced with exactitude. Wild as a large part of the county is the moraine is crossed by more than twenty roads, at each of which it has been identified.

Although a large portion of the county was explored, nowhere was any glacial till found south of the moraine. The small amount of stratified drift in the Allegheny river and in other streams south of the moraine, and the large deposits in streams flowing north from it, indicate that the main drainage of the edge of the ice was *northward* and therefore *sub-glacial*.

*The Coteau du Missouri in Dakota (at the north line of the United States) has an elevation of 2000-2200 feet.

The moraine enters Potter county in the south-eastern corner of *Pike township*, and crosses Pine creek for the second time east of Pike Mills P. O. It is finely shown in crossing Pine creek. Its hills and ridges, covered with boulders, fill the valley to a depth of over 50 feet, and are cut through by the modern creek. Deep deposits of stratified drift occupy the valley from beyond the Tioga county line, but they suddenly end at a point $\frac{1}{2}$ m. E. of Pike Mills. Beyond this, ascending the valley, west of the moraine, no till appears; but a plain of stratified drift, and several interesting *terrace deltas* occur in the valley between here and West Pike P. O.

The moraine, rising upon the hills north of Pine creek some 800 feet above the stream, is next seen on Genesee Forks, which it crosses one mile from its confluence with Pine creek. The moraine is here characterized by high rounded hills covered by boulders, many of which are striated (Spec. No. —).

It is next recognized near Brookland P. O., *Ulysses township*. An abundance of striated pebbles appears here; but, perhaps from the fact that the moraine is in a hollow surrounded by high hills, it is not well shown at this point. The stage road from Brookland to Condersport leaves the glaciated region about a mile west of Brookland.

Entering *Allegheny township*, the moraine crosses a high hill on the line between Ulysses and Allegheny townships one mile south-east of Raymond Corners, 2550 feet A. T. which forms an important water-shed. On different sides of this hill the head-waters of the Allegheny and Genesee rivers and of Pine creek take their rise, the ultimate destination of which is, as already remarked, the Gulf of Mexico, Lake Ontario and Chesapeake Bay.

From this point the moraine descends into the village of Raymond Corners, through which it passes, and ascends a higher hill, north-west of the village, which has an elevation of 2580 A. T. and is part of the same continental divide. This hill is so deeply covered by till that, although steep, no outcrops of rock can be seen. Pebbles of *gneiss* and of *red granite* (Spec. No. —) found in the moraine at this point have been brought from northern New York or from Canada.

Immediately north of it, at 2560 A. T., are knob-like hills and kame-like ridges of sand and water-worn pebbles, indicating a *northern drainage* for the moraine. This is an interesting observation; for, while the general slope is certainly northward, just at this point the ground immediately south of the moraine slopes steeply southward.

The moraine passes westward from here to a point three miles north of Colesburg, where, upon the summit of a hill which forms the water-shed between the Allegheny and the Genessee rivers, and at an 2375 A. T. it is very finely exhibited. It forms indeed a feature in the landscape which can be recognized from a distance. It contrasts strikingly with the region to the south, both in its topography and in its color. All its characteristic features of rounded knob-like hills, with bowl-shaped depressions, striated pebbles and transported boulders, are well displayed at this high elevation. The ground slopes steeply away both north and south. *To the north* towards Ellisburg large deposits of till and of stratified gravel and sand are found, and the latter frequently rise in kame-like ridges bearing N. and S. *To the south* (toward Colesburg) not a single pebble or other sign of drift appears upon the red soil made of the underlying Catskill shales and sandstones. No drift occurs in the small stream flowing from here southward into the Allegheny; and the Allegheny itself, although but three miles away, is perfectly free from drift. Here too therefore *the glacier was drained to the north*.

Several pebbles of gneiss (some 3 inches in length) were found in the moraine at this point.

A small lake known as *Rose Lake* occurs one mile north of the moraine.

A mile farther west the moraine crosses a road at an elevation of 2360 A. T. and is sharply defined. Boulders of gneiss over a foot in length were here found.

The moraine now runs north-west through the north-west corner of Allegheny township.

Entering the S. E. corner of *Oswayo township* it crosses Oswayo creek about a mile east of Oswayo where it is distinguished from any deposits of stratified material in

front of it by the presence of numerous large boulders of coarse sandstone, some of them ten feet long. The moraine has been washed away in the centre of the valley, but is distinct on the north side of the road. The village of Oswayo is not glaciated; but the moraine is distinctly seen about $1\frac{1}{4}$ miles north of the place, upon the summit of the mountain at about 2380 A. T. (Spec. of striated pebble No. —.)

The moraine crosses Eleven Mile creek 5 m. N. E. of Millport. It forms low rounded hills in which striated pebbles (Spec. No. —) are very abundant except at the extreme face of the moraine. The action of water at the front has both rounded the pebbles and carried large masses of stratified gravel down the stream, and into the Oswayo creek at Millport.

The action of water at the extreme end of the moraine is also shown in *Sharon township*. The moraine crosses the north-eastern corner of this township; appearing on Butler creek and at its junction with Honeoye creek; passing close to Goldsmith Corners, north-west of which it is well seen on the road leading towards Little Genesee, N. Y.

It crosses into the State of New York at a point somewhat less than 4 miles E. of the McKean county line.

Deposits of *stratified drift* occur at several places upon Honeoye creek, there being a flat-topped *terrace* (some 30 feet) high at Goldsmith's Corners just south of the moraine. At the junction of Honeoye and Butler creeks the moraine forms a series of rounded hills covered by boulders of sandstone, conglomerate and occasionally *gneiss*, (gneiss boulders nearly one foot long were collected here, Spec. No. —.)

It is interesting to observe that, while striated boulders and pebbles are numerous $\frac{1}{4}$ mile back of the edge of the moraine, just at the edge they are either rounded, or show only traces of scratches, as though these had been more or less worn off by water action. We have here, therefore, at the end of a moraine in a valley, an example of the *transition from till into stratified drift*.

Of the stratified drift deposits south of the moraine in Potter county by far the most interesting are the *terrace*

deltas on Pine creek between Pike mills and West Pike. The moraine probably passes nearly parallel to this portion of the creek, at a distance of about a mile to the north, the absence of roads preventing a more exact statement.

Three small tributary streams enter the creek through ravines on the north side, each of which would have drained the moraine. Pine creek here flows in a gorge some 800 feet deep, the bottom of which is filled with a level-topped deposit of stratified drift. As each of the ravines is approached, a long straight ridge of drift is seen stretching diagonally on the S. E. side of each ravine nearly across the valley. Another ridge somewhat smaller than this appears on the N. W. side of each ravine, running nearly at right angles to the first ridge, but diagonally also to the main valley. These ridges approach each other near the mouth of the ravine, each forming a flat-topped terrace, the lower being some 25 feet high and the upper one about 10 feet lower. The following diagram represents the shape of any one of these: (See Fig. 4, page plate 15, on page 106 above.—See also the three terraces represented on the lower division of page plate map 16, page 128.)

It is evident that each pair of *terrace-tongues* once formed a single *terrace delta*, which was deposited in the main valley by an ice-water stream descending the ravine from the front of the glacier. After the retreat of the ice, the natural drainage of the ravine has cut a channel through its delta and separated the two tongues of drift. A dotted line in the above diagram shows the original connection of the terrace-tongues.

Perhaps of similar origin with these is the curious ridge of drift which about a mile north-west of Genesee Forks runs completely across the valley of Pine creek.

Other deposits of stratified drift are found on Cushing creek and on Oswayo creek, especially at the confluence of streams.*

* [In Switzerland the two lakes at Interlachen have been separated in this manner by glacial detritus shot into the main valley from the side valley of Lauterbrunnen descending from the Jungfrau. In the same manner Lakes Neuchâtel and Bienne have been separated; and careful calculations have fixed the probable date of the *beginning* of the separation at about 5000 B. C. Many other instances might be cited, both in Europe and America.—J. P. L.]

In the central part of the county the drainage of the glacier as already shown was northward. The valley of the Allegheny from the headwaters of the river to below Coudersport is perfectly free from drift. The whole region south of the moraine is a driftless highland cut by deep ravines.†

† [The topography of Potter county is unique, and a proper understanding of it is indispensable for estimating the value of the testimony which the course of the terminal moraine across the county gives to the continental character of the great glacier.

Potter county lies midway between the nearly solid Bituminous coal region of Western Pennsylvania; and the nearly solid Devonian region of North-eastern Pennsylvania, partaking of the characters of both, but differentiating those characters in a series of almost perfectly straight, parallel, alternate Carboniferous mountains and Devonian valleys.

Potter county likewise lies midway between the almost continuous Carboniferous Allegheny mountain plateau of Lycoming on the South and the Devonian region north of the New York State line; exhibiting the characteristic topography of each, but in alternate parallel flat-topped, ravine-cut, rocky, Carboniferous mountain belts, separated by ridged but cultivable lower lands, which are so high above the sea level that, were it not for the mountain belts which separate them, they might be included in the great plateau.

Yet the difference of level between the belts of Carboniferous mountain land and the separating belts of Devonian lower land is everywhere well marked, although amounting to only a few hundred feet.

Seven Carboniferous mountain belts, separated by *five Devonian* lower land belts, traverse Potter county, in a direction almost exactly N. 60° E.

The mountain belts are *synclinal* troughs—the lower land belts are *anticlinal* waves—in the stratification of the country; so that the rock formations of the lower land belts dip gently toward and beneath the higher land belts; yet so gently as nowhere to exceed 5°; seldom exceeding two or three hundred feet to the mile; and in most parts of the county so nearly horizontal that clinometers are useless.

The western half of Tioga county belongs topographically to Potter county; but the valleys of Potter become broader and somewhat lower as they proceed eastward into Tioga county. The south-west corner of Tioga, however, which is crossed by the moraine, is exactly like Potter county.

Now the important fact to be kept in view is this:—the alignment of the terminal moraine diagonally across the south-west corner of Tioga and the whole of Potter county is approximately a straight line; and its direction is N. 55° W.

It traverses, therefore, the seven higher-land, and five lower-land belts, at nearly right angles (85°,) and so to speak without being aware of their existence; for otherwise it would show a series of twelve loops, five of them projecting westward up the valleys, and seven of them receding eastward where it crossed the upland belts.

It is true that the line is not absolutely straight; but its departures appear to be so slight that the statement just made may be accepted as substantially

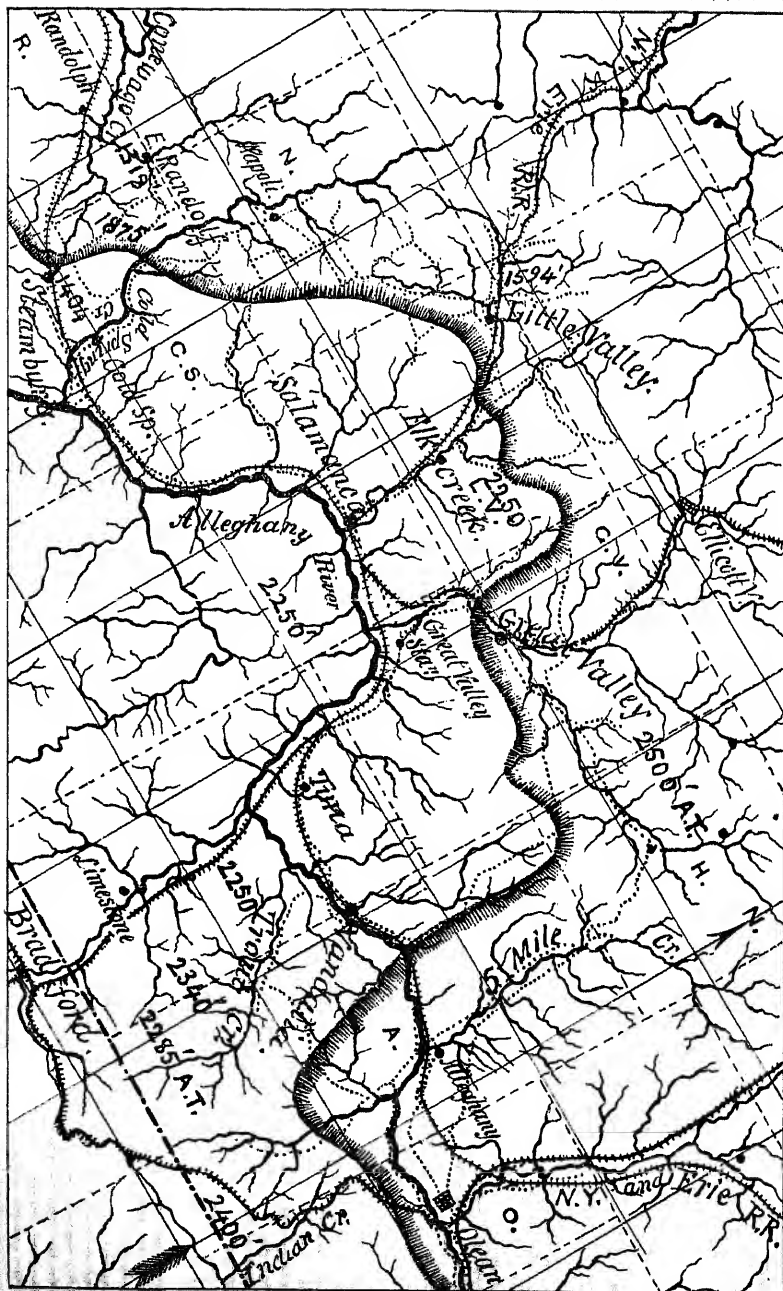
There are elevations in Stewardson township three miles E. of Olean of 2380 and 2400 A. T.; in Sweden township $2\frac{1}{2}$ m. N. E. of Sweden of 2500 A. T. ; and in Hebron township 2 m. N. W. of Hebron of 2370 A. T. The elevations along the line of the moraine have already been given.

correct. Future studies of the line, indeed, may show that whatever slight undulations in the line exist have been caused by the front of the ice advancing a little further south-westward on the lower land, than on the upper; but that is all.

Had the ice sheet stopped in its growth only twenty miles short of the limit which it actually reached, its terminal moraine would no doubt have been approximately parallel to the terminal moraine under consideration; but in that case the moraine would have run diagonally across Tioga county and the south-west corner of Bradford county, a country where the mountain belts are narrower and the separating valleys broader and less elevated above sea level. Consequently the line of such supposed moraine would have exhibited loops similar to those described in the preceding chapters of this report. But still, the *whole line*, taking it from Northampton county clear through to Western New York, is, in spite of its loops, so straight that an addition of three or four hundred feet to the elevation of the land above sea level in Potter county cannot be regarded as in any perceptible degree influential in giving it its oblique north-west direction.

As Professor Lewis suggests in another part of his report, the only conceivable barrier to the further progress of the ice-sheet was an isothermal line of 32° , or whatever higher temperature was necessary to check advance. No such isothermal, indeed, is shown on our physical maps; but that is no sufficient argument against the existence of one in the ice age; nor against the existence of one with a right-angle bend to the south-west in the region west of the Allegheny river. Our present isotherms have long reaches and sharp bends.

No topographical map of Potter county has ever been made; but the topographical features above described can be clearly comprehended by examining the colored geological map of the county published in Report GGG, 1880.—J. P. L.]



CHAPTER XI.

In the State of New York.

Allegany, Cattaraugus and Chautauqua Counties.

The moraine enters the southern counties of New York in the south-western corner of Allegany county; trends north-west to near Little Valley, Cattaraugus county; and then, bending sharply south-west, leaves the State again in the south-eastern corner of Chautauqua county.

This irregular but continuous line, 75 miles in length, is one of the most important portions of the whole moraine.

The moraine is first seen in Bolivar township, Allegany county, somewhat over a mile south-west of Honeoye Corners.

Trending north west it appears upon the water-shed between Little Genesee and Horse creeks at an altitude of about 2200 A. T.

Descending 500 feet, it enters Genesee township and crosses the Little Genesee creek near Little Genesee. In the immediate valley of the creek it has been modified by water action and in part swept away. The village of Little Genesee stands upon a plain of stratified drift.

One mile north-west of the village, it can be distinctly seen in the valley of Windfall creek.

Two and a half miles north-west of this point it appears on the water-shed at the head waters of Deer creek. Here, at the junction of the Deer creek road and a road leading

Fig. 1. Salamanca Rock City. (Chap. XI)

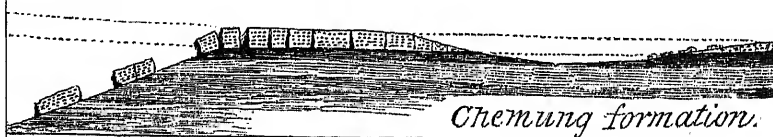


Fig. 2. Kame draining Moraine, Pope Hollow.

Kame. Moraine.



Fig. 3. Section of a Kettle-hole at Freehold. (Ch. XII)

Peat in Kettle hole.



*Fig. 4. Well Section.
(Chapter XII.)*

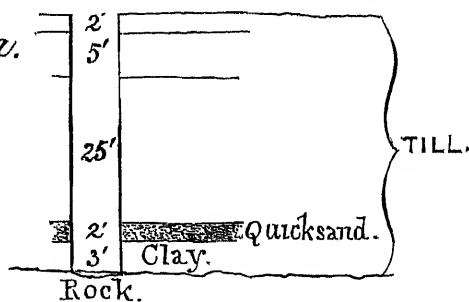
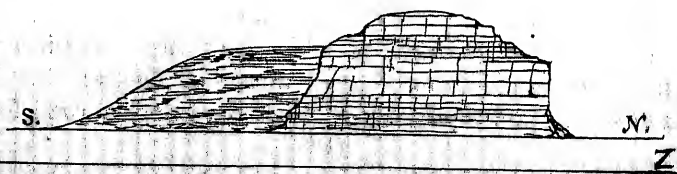


Fig. 5. A double Kame in Mercer Co. (Chap. XV.)



Fig. 6. Stratified drift protected by a crag. (Ch. XVI.)



north toward Dodge's creek, it forms a sharply defined series of drift hills, in which, however, large boulders are more scarce than usual. Immediately north of here it rises to an elevation of 2300 A. T.

The moraine being narrow in this region, and not characterized by large boulders, makes it sometimes difficult to find. North of the moraine in Allegheny county, the soil is filled with sharp fragments of Chemung rocks; it is therefore very similar to that south of the moraine. In addition to this it is often difficult to find striated pebbles or transported boulders just north of the moraine; and frequently *till* is absent over large areas. Farther north, however, as at Cuba and near Friendship, large accumulations of drift appear; but even there large areas occur nearly free from drift.

It is premature here to speculate whether this fact is due to topographical causes, or to a rapid retreat of the ice, or to the presence of another moraine farther north, a "moraine of recession," which formed the southern limit of the ice for the longest period. Weight is given to the latter hypothesis by recent observations in the West (especially in Wisconsin and Minnesota) which have shown these moraines of recession, unfortunately there called "terminal moraines," to be the largest deposits, and therefore to mark the limit of the longest duration of the glacier in one place.

The moraine enters *Cattaraugus county* at the point where Dodge's creek crosses the county line, at the centre of Portville township, and $2\frac{1}{4}$ miles N. E. of Portville, being characterized by an abundance of scratched pebbles. It is best seen on the north side of a bridge on the most western of the two roads leading along the creek. Upon the road on the east side of the creek it is inconspicuous and unrecognizable.

Immediately below the moraine a large deposit of *stratified drift* (at least 40 feet in depth) forms an extensive flat-topped terrace. This continues down the valley of the creek to its mouth on the Allegheny river. The stratified character of this drift is well shown in a deep cut made by the road near Portville. The cemetery at Portville lies upon this terrace, and it is evident that Dodge's creek once formed an important channel of glacial drainage.

The moraine runs north-west to a point upon high hills 3 m. N. of Portville. It makes low rounded hummocks and ridges of till, which contain numerous striated fragments and pebbles, and which continue northward into the valley of Hoskell's creek. The large blocks of conglomerate which lie in the road between Portville and the moraine are in place, and indicate the absence of drift.

The moraine now makes a remarkably sharp curve, bends south-west and crosses the Allegheny river one mile south of Westonville.

In crossing the valley of the Allegheny the moraine forms a magnificent ridge of *stratified gravel*, which stretches across the valley from side to side, and which, 50 feet in height, has been cut through both by the river and by the railroad.

The exposure made by the cut in the Buffalo, N. Y. and Phila. railroad is a quarter of a mile long; it is one of the finest exposures of stratified drift that can anywhere be seen. The normal unstratified condition of the moraine here gives place to a series of alternate layers of sand and gravel, perfectly stratified, and containing no large boulders. An explanation of this unusual condition of the moraine will be offered after a brief description of its course from this point to its second crossing of the Allegheny river, 10 miles further west.

A mile farther west in *Olean township* close to the township line, the moraine appears upon the river road as a drift hill nearly 100 feet high, filled with striated and transported boulders. West of this point, as the moraine attains a higher elevation it loses in great part its distinctive character.

South of Olean the moraine is more poorly developed than probably at any other point along its whole course.

On the road from Olean leading south along the Olean Pipe Line the limit of glacial action occurs at an elevation of 1600 A. T. at a point $1\frac{1}{2}$ miles south of Olean. It is marked by occasional pebbles of *gneiss* and other transported rocks, and by occasional striated fragments, but has no other characteristic features, and is difficult to define. Except for the occasional presence of a rounded pebble the

ground immediately north of the moraine can not be distinguished from the non-glaciated region to the south. The moraine, if it can be called such, is less than 200 feet above the Allegheny river, and may therefore have been washed away by floods of that depth.

A mile and a half farther west, the moraine crosses into *Alleghany township*. It is seen from the road which leads south along the line of the Olean, Bradford and Warren R. R. as a series of very small inconspicuous hills (on the east side of the valley) composed of till and lying at a distance of one mile south of the Allegheny river. Good exposures of till occur on the roadside.

On the next road west, upon Four-Mile run, the moraine is again inconspicuous and known only by the cessation of all rounded pebbles and scratched fragments. It is here two miles south of the river, and about 140 feet above it, (1550 A. T.) Somewhat less than two miles north-west of this point, on a road which runs up a branch of Four-Mile run toward Chipmunk creek, the moraine again appears and then bends north-west toward the river.

It crosses the Allegheny river for the second time at a point near the mouth of Eight-Mile river about 2 m. W. of Alleghany. In crossing the valley of the river it is distinctly seen as a prominent ridge running diagonally across the valley. This ridge is composed in great part of water-worn material, and is a series of rounded hills enclosing shallow depressions. West of this ridge is a level-topped *terrace* of stratified sand and gravel, a mile or more in width. On the south side of the river (crossing an E. and W. road some 2 m. W. of Alleghany) the moraine can be readily distinguished as a ridge stretching from the mountain to the river, and about 75 feet in height. An exposure shows that, while containing a few scratched pebbles, it is composed mostly of a *boulder-bearing clay*, which holds sharp fragments of the underlying Chemung shale, and numerous rounded and water-worn pebbles and boulders of *gneiss*, *granite*, sandstone, conglomerate and other rocks.

We have therefore in that small portion of the moraine which lies south of the Allegheny river two unusual char-

acters—its stratification in the valley, and its very feeble development upon the hills. These characters, and the fact that nowhere does the moraine extend more than two miles south of the present river, suggest the idea that at the time of the greatest southern extension of the glacier the *Allegheny river flowed under the glacier* in the same channel that it now occupies. It is possible that when this triangular tongue of ice, 10 miles broad and 2 miles long, was thrust across the river by the steady advance of the whole front line of the glacier, the river (whose source was to the south) kept open by its warmth a sub-glacial channel, stratifying or washing away the moraine and its boulders as soon as formed. There is indeed evidence in numerous places in Pennsylvania tending to prove that in most river valleys great streams of water were freely moving beneath the ice.

From the mouth of Eight-Mile run the moraine goes nearly *due north* until it reaches the south-western corner of *Humphrey township*, where, upon the northern side of a high ridge, and at an elevation of 2100 A. T. it is finely shown with all its most characteristic features. Rounded hills and hummocks of till, numerous boulders of gneiss, limestone, chert and other rocks from distant northern outcrops, and an abundance of striated pebbles, here form the moraine; while a thick covering of till over the region north, and an entire absence of all drift in the region south, sharply define its course.

The moraine enters *Great Valley township* 2 m. S. W. of this point, and curves slightly southward, so as to cross the southern branch of Wright's creek about 2 m. S. of the main creek. The till is deep, the pebbles and fragments have well-preserved scratches (Spec. No. —), and the moraine is well shown throughout this region.

Pebbles of red granite are now a constant feature of the moraine.

The moraine passes westward toward Peth along the northern base of high hills which rise to 2400 A. T.

The moraine is magnificently shown where it crosses Great Valley creek, $\frac{1}{2}$ mile below the village of Peth. A

great ridge of drift stretches completely across the wide valley. As seen by any one descending the valley it looks like an *immense dam* reaching from side to side. Great Valley creek has cut a channel through this accumulation of drift at the east side of the valley, next to the hill; and the Rochester and State Line railroad makes a fine cut through it, 60 feet deep and an eighth of a mile long. The material composing the moraine is seen to be a true *till* filled with scratched fragments (Spec. No. —) and with pebbles of *gneiss* and *granite*. The elevation of the moraine is here between 1400 and 1500 A. T. and of the highlands on either side from 2200 to 2500 A. T. Immediately south of the moraine is a plain of stratified drift, some of the pebbles of which show scratches only partially obliterated by water (Spec. No. —), thus illustrating *the passage of stratified into unstratified drift*. Numerous observations upon stratified drift have shown that a very slight amount of water-action suffices to erase the striæ from glacial pebbles, and that except where floating ice has been present, no scratched pebbles are to be found south of the glaciated region.

The moraine, although already 14 miles north of the State line, still trends northward. It is finely shown as a series of rounded drift hills in Mutton Hollow, a valley leading north-west from Great Valley P. O. Boulders of granite, gneiss and hard gray syenite are very common. About two miles north-west of the village, in a field near the road, and at an elevation of about 1750 A. T. a large boulder of gray *syenite* (spec. No. —) partially embedded in the ground, measures upon its exposed surface $15 \times 8 \times 8$ feet.

North of this point drift is continuous even upon the highest hills. Upon the hill south of Ellicottville transported and striated pebbles occur at an elevation of 2370 A. T. Immediately west of Ellicottville, at the northern base of the hill are some remarkable accumulations of drift hills which rise to unusual height and are of great extent. They represent the *back* side of the moraine, which here, as in several other places, is more distinct than its front edge.

The southern limit of glacial action, as defined by occasional transported boulders upon the highland, is probably nearly five miles farther south.

In *Little Valley township* the moraine attains its most northern extension. In a valley leading from the village of Little Valley Creek toward Ellicottville the moraine appears as a *ridge of till* stretching across the valley from side to side. It is ascended by the road at a point about $3\frac{1}{2}$ miles south-east of Little Valley P. O. It has here an elevation of about 1820 A. T.

The valley, about $\frac{1}{2}$ mile in width, now occupied by Little Valley creek, leading into the valley of the Allegheny near Salamanca, must have been a great glacial drainage valley. Deposits of stratified drift occur from its mouth up to and into the glaciated region. The moraine, although so modified and leveled off by water action as to make it difficult to fix its precise southern edge, appears to cross the valley at about a mile south of Little Valley P. O. Low hills of unmodified till here lie on both sides of the valley.

Upon the highland south of Little Valley P. O. till, scratched pebbles and a boulder of *gneiss* 3 feet long were found. The last pebbles appear at a height of about 2150 feet above the sea, one mile south of Little Valley. As south of this point no drift whatever was seen, this appears to represent the extreme limit of glacial action.

Two miles south-west of here upon lower ground (1925 A. T.) the moraine is distinctly shown on the line between Little Valley and Napoli townships, about two miles south-west of Little Valley P. O.

From this point onwards through New York and Pennsylvania, to the Ohio line, the moraine trends south-west.

In Little Valley township the eastern and western portions of the moraine have formed approximately a right angle. Owing to the mountainous character of the region, it was not possible to define the course of the moraine as exactly as was wished at this important portion of its course.

The region south of the moraine was explored wherever roads would permit of it in order to become satisfied that it was unglaciated. In one instance only, near the Rock City,

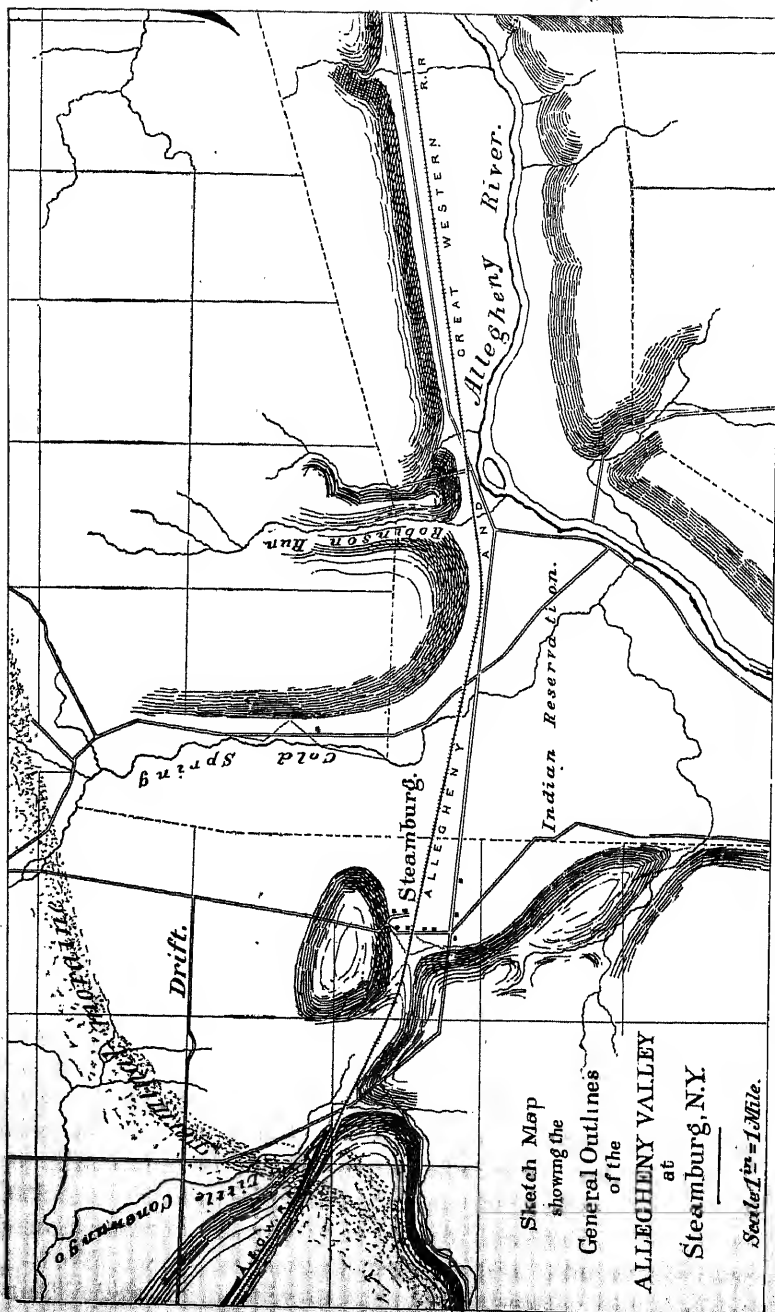
a few boulders and pebbles were found somewhat in advance of the line marked as the moraine.

The *Rock City* is an isolated patch of the Salamanca Conglomerate (Devonian) which caps the top of a hill 2250 feet above the sea and somewhat over 3 miles N. of Salamanca. Huge blocks of the conglomerate, cracked off by the removal of the softer shales below, are creeping down the hill-side in all directions, by the force of gravity, aided by frost and rain. They creep northward as well as southward keeping vertical as they slide. (See Fig. 1, page-plate 18, page 150.)

There are no signs of glaciation at the Rock City. The moraine is several miles to the north; yet on the north side of the hill, at an elevation of 2070 A. T., a striated fragment of Chemung shale was found. Immediately south of the rocks, $2\frac{1}{2}$ miles from Salamanca, at an elevation of 2010, a boulder of *syenite* measuring 4×3 feet was discovered. In a valley to the east leading toward Peth are other occasional transported pebbles. It seems as if a small portion of the ice extended over these hills a mile or so in advance of the moraine and the deposits of till; or that the extreme front of the moraine was here not so definitely marked as its back near Ellicottville.

The moraine, entering *Napoli township* about two miles south-west of Little Valley P. O. and, passing in a south-west direction two miles east of Napoli, reaches the line of *Cold Spring township* at a point about $2\frac{1}{2}$ miles south-east of Napoli.

In the south-east part of *Napoli township* the moraine is finely developed, as a series of ridges rising one above the other, a mile in width and at an altitude of about 1900 A. T., resting against a hill of about 2000 A. T. It incloses kettle-holes filled with *peat*, and has other characteristic features. At another place, less than a mile away from the last, and about two miles south-east of Napoli P. O., the moraine rises distinctly in knob-like hills to a height of 2000 A. T. at its extreme edge, and is covered by transported gneissic pebbles and striated fragments, (Spec. No. —), while a hill perfectly free from all drift and 2100 A. T. im-



mediately adjoins it on the south. It is instructive to see the moraine here lapping up on a driftless hill, and ending suddenly, at an elevation of 2000 A. T. A single *gneissic pebble* lay at a height of 2050 A. T.

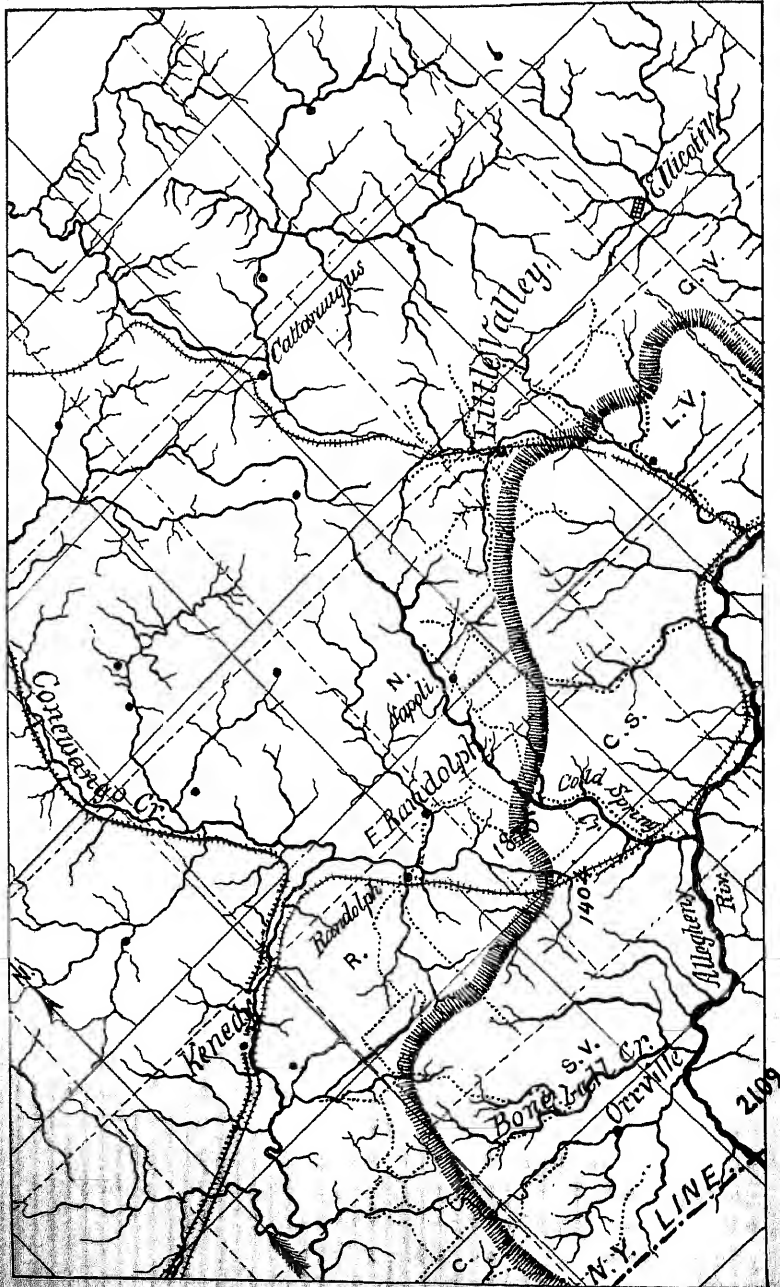
An examination of the region for five miles east of this point showed an entire absence of any signs of glaciation.

In *Cold Spring township* the moraine is readily recognized where crossing Cold Spring creek, and on the line of the Atlantic and Great Western R. R. west of Steamburg. A ridge of till containing scratched pebbles crosses diagonally the valley of Cold Spring creek, about 3 miles N. of Steamburg, near the meeting of three roads. It is about half a mile wide, and has been modified and leveled down by floods coming down the valley. A level plain of *stratified drift* fills the broad valley in front of it and extends down the creek to the Allegheny river. North of the moraine occasional ridges of till occur, but, except on the north sides of hills, the till is generally a thin covering, and is often absent. Large boulders are scarce.

The village of Steamburg on the Atlantic and Great Western R. R. is on a great plain of stratified drift, which is at least 70 feet in depth as shown by wells, and which contains many large boulders of *gneiss*. Ridges of the same material occur close to the village. One of these is terminated by a conical hill, a fine section of which (recently cut) shows it to be composed of water-worn gravel cemented firmly by lime and overlaid by a clayey loam holding large boulders. [See Map, page-plate 19, page 158.]

It seems that after the inner material had been formed by rapidly flowing glacial waters, possibly under the ice, it had been submerged by deeper waters, and the boulders dropped upon it from the melting or floating ice. No modified drift occurs south or east of Steamburg, which forms the limit of glacial action. West of it fine moraine hills appear in the valley, and are finely developed, with all their most characteristic features, upon the high hills to the southwest. The moraine crosses the railroad, probably, somewhat over a mile west of the village.

The whole valley from here to Randolph has the appear-



ance of having been a great drainage channel in glacial times.

The moraine is magnificently shown in *Randolph township* $3\frac{1}{2}$ m. S. of the town of Randolph. It rests upon the northern slope of a high hill some 2100 feet above tide, and rising upon it to a height of 2040 feet A. T., or 680 feet above the valley at Randolph. The moraine appears with all of its characteristic topographical features of ridges, hummocks, shallow depressions and kettle-holes, swamps, etc., and is composed of a *typical till* filled with scratched fragments, and bearing large boulders of *gneiss* and of other rocks transported from great distances. The moraine is about two miles wide, and consists of a succession of ridges often 50 feet high, while the knob-like hills rise yet higher. The road from Randolph southward exposes good sections of till 15-20 feet in depth. The precise edge of the moraine, as it rests against a hill on top of which is not a trace of drift, can be fixed with great exactness within a few yards.

This is a most instructive locality, and worthy of a visit from any one interested in glacial geology.

In order to form this moraine the glacier must have been at least *700 feet thick at its very edge*.

From this point westward and south-westward as far as the Pennsylvania State line the moraine lies upon the watershed between the Allegheny and the Conewango rivers.

The moraine is conspicuously shown throughout the remainder of its course in Cattaraugus county, and is readily defined upon the several roads which cross it. The village of Mud Creek in the S. W. corner of Randolph township is built upon a portion of the moraine, which is here a distinct ridge of till, upon which *gneissic boulders* are numerous. The moraine here turns south and passes into South Valley township about half a mile east of the Chautauqua county line.

In *South Valley township* the moraine skirts along its western line for two miles, keeping within half a mile of the county line until just south of Pope run it enters Chautauqua county. Nearly the whole of South Valley township is therefore unglaciated.

In "Pope Hollow," close to the line between South Valley township, Cattaraugus county, and Carroll township, Chautauqua county, and resting upon the water-shed between Pope run (a tributary of the Allegheny) and Case run (a tributary of the Conewango) the moraine is finely shown as a ridge of till which, stretching completely across the valley, and covered by numerous boulders of *gneiss*, rises upon the highlands on either side.

The moraine ridge here, as upon Fishing creek, Columbia county, Pa., and other places, is most prominent *behind* or towards the west.

A very small *kame* runs westward from the back of the moraine in Chautauqua county, and appears to be the result of a sub-glacial stream which drained the moraine backwards into the valley of the Conewango. Although the moraine lies in the middle of a valley, on either side of which the hills rise 800 feet, although the valley has a continuous downward slope eastward to the Allegheny river, the moraine breaks off suddenly and completely at the highest part of the valley, and not a trace of drift occurs east of it. The moraine is unmodified by water, and is limited in this valley as suddenly as it is upon the high land south of Randolph. The ice which was bounded by this moraine certainly flowed in a very different manner from water. Fig. 2, page plate 18, page 150, represents the moraine and its draining-kame at the boundary line of Cattaraugus and Chautauqua counties.

Upon the high land immediately south of this point, and 600 feet above it, the moraine is again distinctly seen; the evidence is therefore strong that the glacier must have been at this point of its edge at least 700 feet thick.

In *Chautauqua county, Carroll township*, upon both of the roads leading from Frewsburg to Onoville, the moraine is distinctly marked, fixing the exact limit of glacial action at three quarters of a mile west of the county line.

The south-western corner of Cattaraugus county is a wild, heavily-wooded, elevated region, deeply cut by ravines and perfectly free from any signs of glaciation. Upon going from this region westward into Chautauqua county the sud-

denness with which the moraine is encountered is surprising, the whole face of the country being changed when the glaci-ated region is entered upon. The till has rendered the country much more fertile, and the dense forests found in the non-glaci-ated region rarely occur. The ravines and val-leys have also been more or less filled up; the rocks are often covered by drift; and the streams flow more sluggishly.

The moraine itself in Carroll township crosses the upper road from Frewsburg to Onoville at an elevation of 1875 A. T.; and the southern road between these two villages at an elevation of 1975 A. T. Still trending directly south it is seen $\frac{1}{4}$ m. north of the Pennsylvania line at an elevation of 1975 A. T. and crosses into Pennsylvania at a small creek known as Storehouse run, less than a mile west of the Cat-taraugus county line, at an elevation of 1700 A. T. Striated fragments of Chemung shale (Spec. No. —) and numerous large transported boulders here cover the rounded hills, which sharply define the moraine. Boulders of *gneiss* have now become very common; and an occasional boulder of *granite* is found.

The moraine has thus far had a nearly north and south course for seven miles north of the Pennsylvania line, being throughout a distinct accumulation of drift sharply sepa-rating the glaci-ated from the non-glaci-ated regions.

The general course of the moraine is remarkably similar to that of the Allegheny river; and since this similarity persists in Pennsylvania throughout the whole course of the river, the fact must be something more than a mere coincidence.

In New York the valleys of Dodge's creek, Great Valley creek, Little Valley creek and Cold Spring creek have drained the moraine into the Allegheny river and are now deeply filled with *stratified drift*. The deposit in each of these valleys consists of a level plain, which often rises into ridges at the entrance of side valleys, and *terrace deltas* are often seen. Frequently the drift-plain shows shallow fur-rows and ridges, running parallel with the valley, which are evidently the result of water action on a large scale mould-ing the surface of the plain. The large deposits of drift

which generally occur at the mouth of any glacial drainage valley, are most prominent on the *lower* (down stream) side of the valley, conforming to the facts already noticed (on a smaller scale) on the Lycoming creek and elsewhere. Thus, at the point where Great Valley creek empties into the Allegheny, the drift forms the largest and deepest deposit on the western side of the valley, a fact evidently due to the action of the westward flow of the Allegheny river.

Some of the drift ridges which cross a valley filled with stratified material are not readily explained. A curious ridge of drift at the village of Little Valley Creek stretches across the valley like an artificial dam and is covered by boulders of gneiss. Being close to the moraine there is some uncertainty whether it is due to the action of ice or of water. Two valleys meet just above the ridge.

Except in such valleys the region south of the moraine is perfectly free from drift. The only rounded pebbles which occur on the high ground of southern Cattaraugus and of McKean county, Pa., are those which are weathered out of the coarse conglomerate underlying them.

North of the moraine there are proofs of universal glaciation. The great accumulations of *till* which, at many places, form ridges higher than that of the terminal moraine probably represent *moraines of recession*; and future investigation will doubtless be able to connect many of them so as to form continuous moraines, which will mark the boundary of the ice-sheet at halting-places in its retreat.

Morainic hills of this character may be seen at a number of places in Allegany county, and elsewhere, and are well worthy of future study. They occur for example along the line of the N. Y. and Lake Erie R. R. near Hinsdale and elsewhere. At Hinsdale the railroad makes several cuts through an accumulation which is several miles in length and contains large boulders.

Disconnected accumulations of *unstratified till* also frequently occur in valleys filled with *stratified drift*; and numerous examples might be given.

Thus in the valley of Haskell's creek, which is a level plain of stratified sandy drift, there occurs (2½ miles from its

mouth) a conspicuous ridge of till which crosses the valley and rises upon the slopes in rounded hills like a moraine.

Similar phenomena occur in numerous other places.

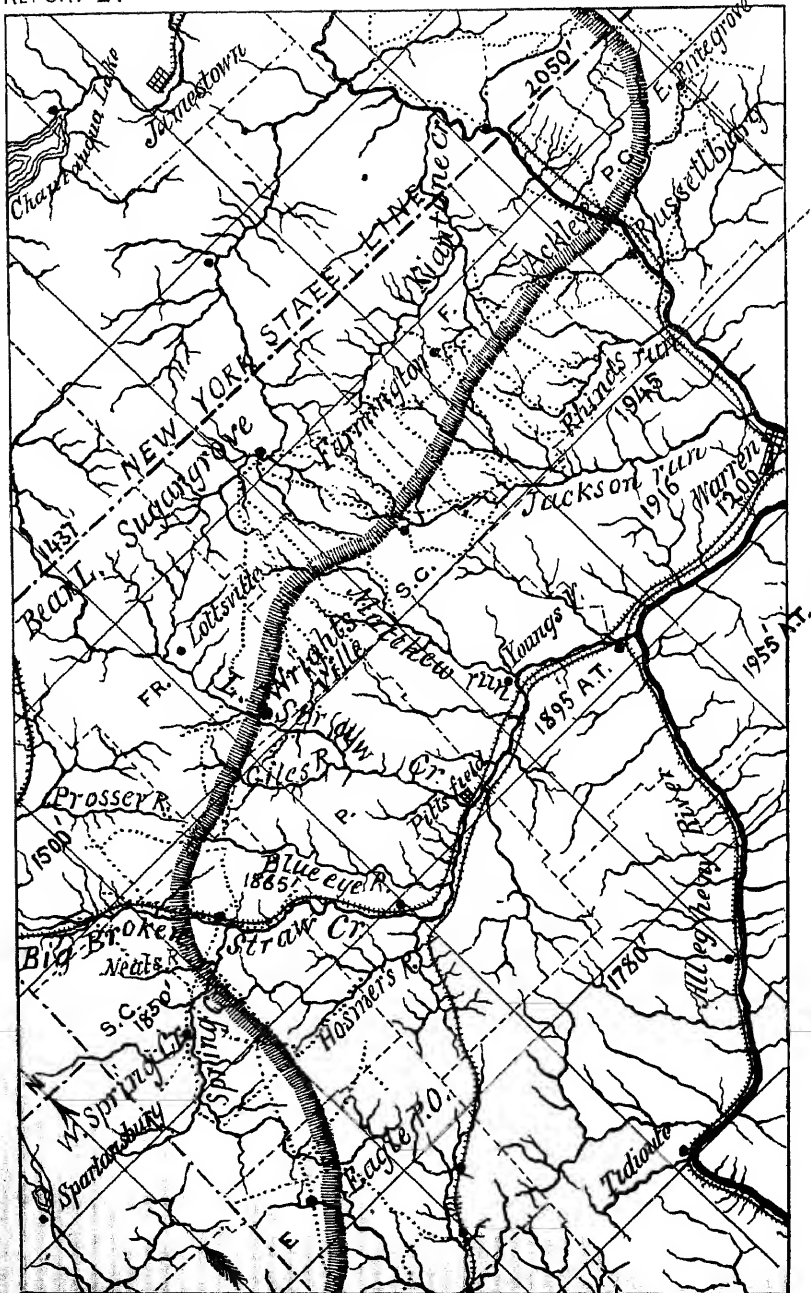
Kame-like ridges of stratified material are of frequent occurrence along the valleys and are often prominent features. They are generally parallel to modern water-courses, although occasionally considerably removed from any streams.

Of the kames near the moraine, that which lies in the valley of the Conewango river (well shown where crossed by the Atlantic and Great Western railroad), and that which extends along Whitney valley (conspicuous between Alfred and Almond on the Erie Railway) are two of the most noticeable. The latter is finely developed, with characteristic contours, and of considerable height.

[NOTE.—Mr. Lewis necessarily confined his observations to a comparatively narrow belt of country in New York State, along the line of the moraine.

Mr. Carl's observations, in previous years, covering extensive districts north and south of the State line, and peculiarly valuable on account of his familiarity with both the topography and geology of the country, have been published in his Third Report, (III, 1880,) and in his Fourth Report, (VIII, 1883.) His careful descriptions of critical localities and the important deductions which he draws from the topographical and glacial features of the region need only this reference. The reader must consult Report III.

The local map of the vicinity of Steamburg, in Cold Spring township, Cattaraugus county, taken from Report III, 1880, page 341, is inserted in this report on page 158.—On this map Mr. Lewis's line of the terminal moraine has been added where it crosses Cold Spring creek and the Little Conewango.—J. P. L.]



CHAPTER XII.

In Warren county.

The moraine enters Warren county on the New York line $7\frac{1}{2}$ miles west of McKean county.

Of the northern tier of counties McKean was thus the only one which the glacier did not enter.

The glacier has been of great advantage to that strip of Warren county which it once covered. It has made a fine farming land of a wild unfertile region. The deep covering of soil which the glacier brought with it has proved to be, notwithstanding the accompanying boulders, much better adapted for agricultural purposes than the thin soil south of the moraine produced by the decomposition of the underlying rock. The moraine separates regions of widely different characters. *South* of the moraine there is a wild, heavily-wooded region, consisting of higher land cut by deep ravines, whose steep hills on either side are difficult to traverse yet are most picturesque. *North* of the moraine a cultivated, rolling country, of more gradual slopes and more sluggish streams, is covered by a clayey, boulder-bearing, yellow soil, which has no wild scenery, but is more useful to the farmer than the region never covered by the glacier. This agricultural significance of the moraine is shown in several of the western counties.

The moraine appears first in *Pine Grove township* at a point 2 m. N. of East Pine Grove P. O. close to the Elk township line.

Curving south-west, it crosses the Conewango river at Ackley, and then runs directly west into Farmington.

The moraine is finely shown and has very interesting features at the point where it crosses the Conewango river. As viewed from the north, the moraine ridge, filled with scratched stones and dotted with numerous boulders of *gneiss*, can be seen coming diagonally down the hills east of the river, stretching completely across the valley just below Ackley station, and rising again upon the hills to the west. The moraine descends about 800 feet to cross the valley of the river, here 1230 feet above the sea. The moraine forms a ridge some 75 feet in height, which rises sharply out of the drift-filled valley to the north. The southern edge of the moraine merges into a vast deposit of *stratified drift* which, heaped up into hummocks and ridges and terraces, completely fills the valley of the river for two or more miles south of the moraine.

At Russellburg, one mile below the moraine, great accumulations of coarse water-worn gravel, more than 100 feet high, rise on both sides of the river, in long irregular kame-like ridges, often enclosing *kettle-holes*. Numerous exposures show only a very slight stratification, as though deposited all at once by a rushing flood. High terraces and extensive plains of the same material occur, and the ridges are finer than the writer has noticed at any other place south of the moraine. Farther down the river the ridges sink into more level plains of drift; but become yet larger closer to the moraine. At about a half mile south of the moraine the pebbles in this drift show occasionally indistinct glacial striations, being here only partially water-worn, and thus illustrating the transition into the unstratified drift of the moraine. The moraine itself is easily recognized by the numerous boulders of *gneiss* which cover it.

As it rises upon the high hills bordering the valley it shows its usual rounded knobs and ridges.

On the east side of the river it follows up a branch of Jackson run, and is seen for over a mile along the road from Ackley leading east.

In *Elk township* which shows no signs of glaciation, the

ground rises to 2150 A. T. The pebbles (sometimes 4 inches long) which are weathered out of the underlying conglomerate should not be mistaken for glacial pebbles. It was of interest to find that in several places in front of the moraine ridge, sometimes half a mile distant, there were found numerous transported boulders of sandstone and conglomerate, both rounded and sharp and sometimes striated, with also occasional pebbles of gneiss, as though the extreme *edge of the moraine thinned out* for half a mile.

The Conewango river north of the moraine is a somewhat sluggish stream, bordered by occasional swamps, and flowing in a valley in which there are no rock exposures on account of the deep covering of till. Boulders are scarce, and the till is so filled with sharp fragments of shale that it looks more like a broken rock in place than like till. The till of the moraine has a much more typical character.

West of the river and through *Farmington township* the moraine is finely shown at numerous points. At the line between Pine Grove and Farmington townships, about 3 m. E. of Farmington Center (Lander P. O.) the moraine is typically developed in hummocks and kettle-holes, covered by numerous and large boulders of *gneiss*, *granite*, and other rock, one of which—a boulder of *gneiss*—measures 9×7 feet. The moraine, as is usual in this county, forms a water-shed between streams flowing in opposite directions. Gneiss boulders and low hills of drift extend for nearly half a mile S. E. of the main ridge of the moraine.

Passing about 1½ m. S. of Farmington Center the moraine, still going westward, crosses into *Sugar Grove township* a mile E. of Chandler's Valley P. O. Boulders are comparatively scarce in this portion of the moraine. (It will be found that azoic boulders become much more numerous in counties farther on.) North of the moraine a thick covering of till fills the valleys and makes gentle slopes. Wells 30 feet in depth are said to fail to get through the drift at Farmington Center. A "blue clay" is reported at the lower part of these wells.

The valley of Jackson run, south of the moraine, contains terraces and terrace deltas of stratified drift, which are

especially prominent at the entrance of streams from the north which have drained the moraine.

Moving westward through the lower part of Sugar Grove township, it passes about $3\frac{1}{2}$ m. S. of Sugar Grove P. O.

It is finely shown at Chandler's Valley P. O. in the valley of Jackson's run. It is here at least a mile wide, and fills up the valley so as to form a divide between streams flowing N. and S. It forms irregular hummocks and ridges and near the Swedish Church in the village the back part of the moraine exhibits sandy ridges, conical hills, and kettle-holes. It is important to observe that in this valley as elsewhere the glacier did not form tongues stretching down the valley. Indeed, the reverse was frequently the case, since the moraine often advances farther south upon the hills bordering a valley than in the valley itself.

Upon the hills south-east of the moraine at Chandler's Valley there is no till, and boulders are scarce, but extend nevertheless a mile or more below the moraine, so that occasional transported boulders of sandstone, gneiss and granite (sometimes two feet in diameter), and occasional glacial fragments, can be found scattered upon the surface.

This *fringe* of scattered boulders in front of the true till is of very limited extent. There is here no trace of it at a distance of 2 miles from the moraine ridge; and an extended examination of the high region farther south showed that to be perfectly free from drift. The occasional blocks of sandstone and conglomerate which rest upon the shales come from neighboring outcrops.

The moraine is distinctly tracable on top of a ridge known as Pike's Ridge (about 1950 A. T.) three miles south-west of Sugar Grove P. O. A ridge of till covered with numerous boulders, many of which are of gray gneiss, lies upon the northern slope of this high ridge, coming to an end at the summit. (Spec. of striated pebble No. —.)

The S.E. corner of *Freehold township* is crossed by the moraine, here trending S. W. nearly parallel to the State road.*

* [See Mr. Carll's spirit-level profile of the State Road, surveyed by him in 1875; Plates 3A, 3B, Atlas to Report III, 1880; and described in Chap. 2, p. 11, Report III, 1880.—See also his description of isolated hill, drift dams and pond, in Report III, 1883, p. 231.—J. P. L.]

Upon descending a branch of the Little Brokenstraw creek from the State road, there is found, less than $\frac{1}{2}$ m. S. E. of that road, and about one mile N. W. of Freehold P. O. a sharp ridge of till, holding glaciated pebbles, and stretching across the valley. This ridge, like the one first described on Fishing creek, Lycoming county, appears to form the *back* of the moraine and to make it steeper and more sudden than the front edge. South-east of this ridge a series of lower drift hills extends irregularly to Freehold P. O. forming the front of the moraine. The creek has made a sharp narrow cut through the moraine ridge.

An interesting exposure occurs at the village of Freehold by a cut through the edge of a *kettle-hole* made by the road. The kettle-hole lies in a terrace of *stratified gravel* which lies about 40 feet above the creek. The latter has worn a channel through the gravel. The kettle-hole is shown to be filled with a deposit of *peat* (6 feet thick where exposed) and holding in its lower portion numerous logs of trees, probably hemlock. Below the peat and between it and the stratified gravel is a deposit of yellow till, which, where in contact with the peat, for a depth of some 5 feet, has become bluish-gray. This is evidently due to the deoxidation of the iron in the till by the organic matter of the peat. It is probable that all "blue till" or "lower till" is merely the unoxidized portion of the till. (See Fig. 3, page-plate 18, page 150.)

South of the moraine very occasional transported and striated pebbles indicate that a *fringe* continues for a short distance below it.

The pebbly soil which occurs upon some of the hill tops east of here must not be mistaken for drift. It is the result of a thorough decomposition of the underlying very coarse white conglomerate (XII).

North of the moraine a deep covering of till, with numerous *azoic* boulders, occurs at all elevations. The high hills on the State road, 1900 feet above the sea and distant about a mile from the moraine, are thus covered.

The moraine enters *Spring Creek township* at its N. E. corner, crosses Big Brokenstraw creek near the confluence

of Spring creek, and bending to the south at this point crosses the line of Eldred township near its centre. The moraine is represented in the valley of Big Brokenstraw creek by large accumulations of stratified drift.

At Garland and for nearly 4 miles above that town the valley of the creek contains no terraces, and the absence of drift is remarkable considering the proximity of the moraine. Four miles above Garland a heap of stratified drift, 40 feet in height, occurs where the road crosses the R. R.; and from here northward *terraces* appear. Just before reaching Spring Creek P. O. the R. R. cuts through large accumulations of *stratified drift*, containing large boulders. Unstratified till does not occur for more than a mile further north.

The interesting fact is here shown that so far from the glacier having projected a tongue of ice down the valley, as would be expected, the front edge of the ice has fallen back.

It is not improbable that an immense cave, kept open by the warmth of the air and water, extended back into the glacier, whence a great stream issued at the time of the melting of the glacier.

Upon the hills on either side of Big Brokenstraw creek the moraine, made of unstratified drift, extends nearly as far south as the stratified deposits in the valley. The State road passes over deposits of till on both sides of the creek. Between Spring Creek P. O. and West Spring Creek P. O. the State road, after passing some hills of stratified drift, crosses a ridge of till which, holding numerous striated boulders and fragments (Spec. No. —,) runs across the valley of Spring Creek like an artificial dam and perhaps forms the back end of the moraine. This point is about $1\frac{1}{2}$ m. S. W. of the crossing of Big Brokenstraw creek.

North of here is a deep covering of till. In the S. E. corner of *Columbus township* till and boulders cover the rock deeply, even upon the tops of the hills 1900 feet above the sea. Boulders of *granite* 5 feet in diameter were found here. Several wells upon this high ground showed that the drift is often over 25 feet in depth. Alternations of a stiff boulder-bearing clay and a quicksand occur with no regularity of succession and show the presence of water below

the ice. The section of a well given in Fig. 4, page plate 18, page 150, is probably a typical one and illustrates the occurrence of aqueous deposits below the till.

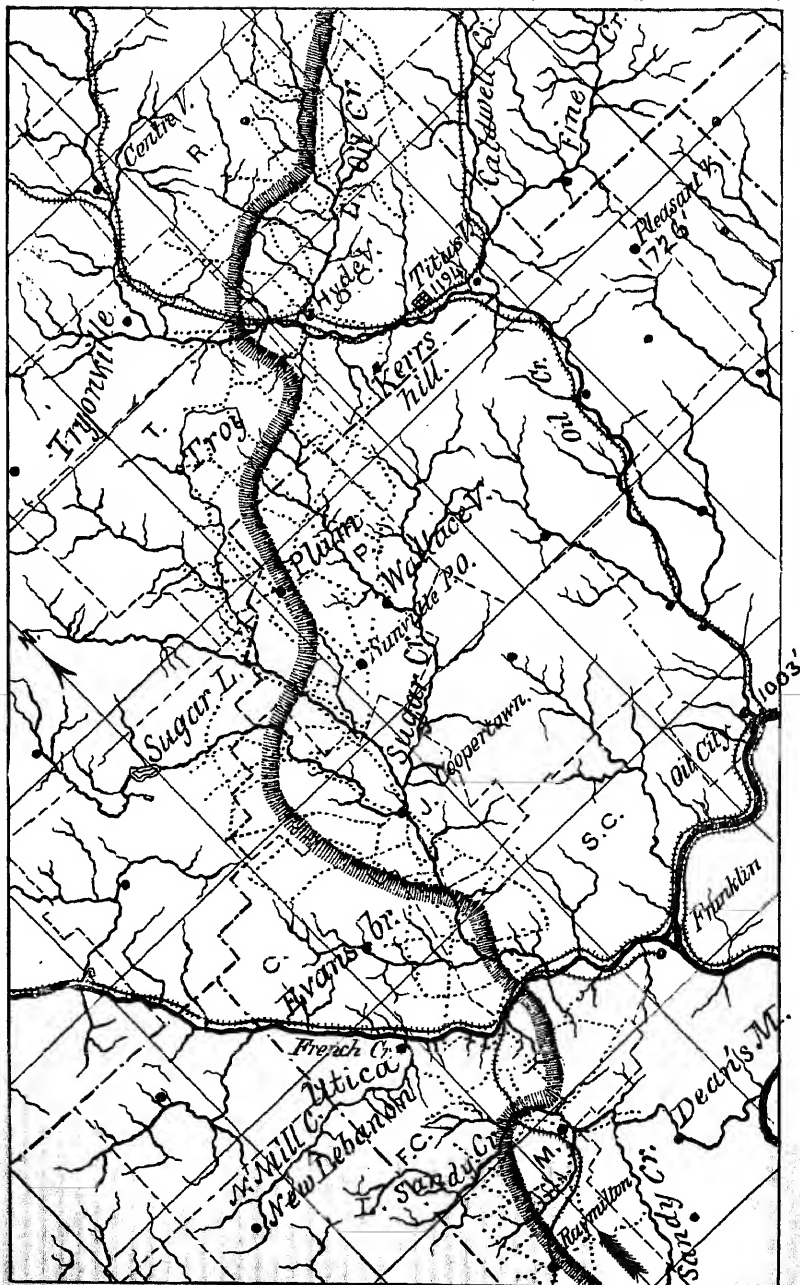
Sometimes the sand is entirely absent and sometimes it is found within a few feet of the surface. The water found in the wells is said to "go in streaks." Sometimes it occurs in strata of sand or gravel in the drift at a depth of 12-15 feet; at other times it is necessary to bore into the rock 100 ft. or more below the drift before water is found.

The moraine enters *Eldred township* $2\frac{1}{2}$ m. N. E. of Eagle P. O., passes within a mile to the east of that place, and crosses the Crawford county line 3 miles S. W. of the same village. Throughout a great portion of its course in this township it passes through a primeval forest, but can always be recognized by the accumulation of boulders which suddenly cease at its S. E. edge. Its general elevation is here about 1800 A. T. Less than a mile E. of the Spring Creek road it forms rounded hills, covered with boulders. It crosses the same road about 3 m. S. of Eagle P. O. and is there marked by the occurrence of numerous *sandstone* boulders, often of very large size. Boulders of *gneiss* are also frequent.

South of the moraine for somewhat over a mile occasional striated sharp fragments of sandstone can be found which appear to be the result of ice action. Farther south no drift whatever occurs. This narrow *fringe* appears now to have become a nearly constant feature of the moraine.

The contrast between the wild wooded region in front of the moraine and the fertile land back of it, already mentioned, is well shown in this township.

Of the phenomena exhibited by the moraine in Warren county there are three especially worthy of note: (1.) Its agricultural significance. (2.) The gradual development of a morainic *fringe*. (3.) Valley deposits indicative of glacial caverns rather than tongues.



CHAPTER XIII.

In Crawford county.

The undulating line of the moraine crosses the southeastern corner of Crawford county in a general south-west direction. It enters *Rome township* 3 m. E. of Morris Corners and passing for the most part through deep woods is especially noticeable where crossing Thompson's brook and McLaughlin creek. At the latter place, close to the line of Oil Creek township, are fine conical hills and kame-like ridges of sandy stratified drift and numerous boulders. Frequent *kettle-holes* occur here; and upon the high hills in the east are a series of ridges of till, covered by boulders of *gneiss* and *granite*.

The moraine crosses the N. W. corner of *Oil Creek township*, where an accumulation of azoic boulders characterizes it upon the higher ground. It has especially interesting features at the point where it crosses Oil creek, near the corner of Steuben and Troy townships. Behaving very much as it did in crossing the Conewango in Warren county, it comes down from the highlands on either side in a clearly marked series of ridges and hummocks, to the valley of the creek (400-500 feet below the general level) which it fills with great accumulations of water-worn drift, extending for several miles along the valley. Titusville, nearly 5 miles below the moraine, is built upon a level *terrace* of stratified material, over a mile wide, and about 100 feet deep. A second and higher terrace appears at the upper end of the

(175 Z.)

city, forming the wide, level plain upon which the race-course and the cemetery are placed. These terraces continue up the river, becoming higher and more irregular at Oil Creek P. O. (Hydetown,) until, a mile or two above that place, they rise into the ridges and hummocks which characterize *stratified drift* at the base of the moraine. No true till was noticed in the immediate valley, the pebbles being all water-worn. The valley where crossed by the moraine is at an elevation of 1250 A. T.

In *Troy township*, on the hills south-west of Oil creek, the moraine can be traced at first southward and afterward south west, being at an elevation of about 1700 A. T.

A boulder of gray *syenite*, measuring 8×6 as exposed (Spec. No. —) was found upon the low, rounded accumulations of till and boulders which form the moraine upon the hills in the north-east corner of this township. Striated pebbles and fragments of fossiliferous Chemung shale are here abundant. (Spec. No. —.)

Near the Venango county line the moraine passes $1\frac{1}{2}$ m. N. and N. W. of Diamond P. O., where it is characterized principally by the abundance of *gneissic boulders*. These are a hornblendic and slaty stratified gneiss, sometimes containing bronzite, and generally of a gray or brown color. One of them is 5 feet in diameter. The boulders of *red granite*, which will be found to be so abundant in counties farther south-west, are here absent, or very scarce.*

*[NOTE.—In 1880 Mr. I. C. White surveyed Crawford and Erie counties, after having studied the glacial phenomena of Beaver, Lawrence, and Mercer in 1877, 1878 and 1879. He summarizes his observations in his Report on Crawford and Erie, (1881,) Chapter 3, page 29 ff.—The highest glaciated point which he encountered was 1750' A. T. There are hill-tops at the east of Erie county, 1850' A. T., on which he could see neither drift nor boulders (page 30.)—The top of College Hill at Meadville, 1550' A. T. (1177' above L. Erie) is scratched.—The *direction of scratches* on 30 or 40 hill-tops he found to be *uniformly* about S. 30° E. (page 31.)—*Erratics* are abundant (some of them 10 feet in diameter) but nothing like so numerous as in Mercer, Lawrence and Beaver counties (page 33.)—*Ancient valleys* deeply buried in drift he describes on pages 33 to 40.—*Peat and Marl beds* on pages 40 to 42.

Mr. Carl's much earlier investigations of the buried valleys of N. W. Pennsylvania, resulting in his discovery of the *pre-glacial* drainage of the region northward into Lake Erie, are elaborately described and illustrated with maps, &c., in his reports (III, IIII.)—J. P. L.]

In several places in front of the moraine in Crawford county occasional transported boulders and sharp fragments are found as a narrow *fringe*. Back of the moraine the till is often so filled with sharp fragments of the underlying shale as to look in many places like an unglaciated region. The till is frequently so deep as to completely cover over the underlying rocks; and the valleys have been so filled with drift as to form many swamps, and occasional ponds. By this widening and raising of the valleys, not by any *planing* action of the glacier upon the hill-tops, has the general elevation of the glaciated region been rendered more uniform than that of the region south of the moraine.

CHAPTER XIV.

In Venango county.

The course of the moraine for nearly 40 miles is close to the western boundary of the county, at a mean elevation of somewhat over 1500 A. T. or 925 feet above Lake Erie.

The constant presence of a moraine *fringe*, 3 miles wide, is especially to be noted in this county.

The moraine first appears about a mile N. W. of Diamond P. O. in *Plum township*, close to the line of Crawford county, being represented by an accumulation of azoic boulders rather than by any characteristic topography. Crossing the turnpike $\frac{1}{2}$ m. E. of Plum P. O. (Chapmansville,) it passes between Plum and Sunville and, turning westward, crosses the E. branch of Sugar creek somewhat more than a mile N. W. of Sunville, and reaches the line of Jackson township at a point a mile N. E. of Wilson's Mills P. O., being here less than a mile distant from the zigzag boundary of Crawford county.

In *Jackson township* the moraine is finely shown where it crosses the W. branch of Sugar creek, less than a mile from the Crawford county line. High hills of unmodified

till of characteristic contour and covered by boulders (many of which are azoic) rise on both sides of the creek near Wilson's Mills P. O. Bending southward, the moraine now passes into a forest, through which it was traced by the large size of its boulders. It then follows Beatty's run in a direction somewhat east of south, and passes 2 m. W. of Coopertown, close to the line between Jackson and Canal townships, where it is distinctly marked.

Entering the N. W. corner of *Sugar Creek township*, 2 m. S. W. of Coopertown, it is finely developed in conical hills in the valley of Sugar creek. The moraine crosses the creek diagonally and has caused a level-topped terrace immediately below it. Upon the hill E. of the creek the moraine is readily traced by the *accumulation of granitic and gneissic boulders*, some of which are over 6 feet in length. Passing about $\frac{1}{2}$ m. E. of Old Valley Furnace the moraine reaches French creek at a point between 3 and 4 m. N. W. of Franklin. *Terraces* here are seen on both sides of the stream; and rounded, irregular hills of till, covered with sandstone boulders, indicate the point where the moraine crosses the valley. Good exposures of the moraine are made by the Lake Shore & Michigan Southern R. R. on the south side of the creek; and the point where the plain of *stratified drift* suddenly rises into *hills of till* can be readily seen from the car windows. The till here, as generally in Venango county, is sandy, having been formed from the underlying sandstone rock. Most of its boulders and pebbles are of the same sandstone. Hills of till also occur on the northern side of French creek near the mouth of Sugar creek. French creek where crossed by the moraine is at an elevation of about 1050 A. T.; the hills on either side rise probably 400 feet higher.

In *French Creek township*, upon the low water-shed between French creek and Little Sandy creek, the moraine is finely developed, and forms a broad and deep accumulation of till, which crosses the valley, diagonally, in a series of ridges, and which laps upon the hills on each side in characteristic hummocks and hollows.

The railroad passes through it by several cuts, one of

which is nearly $\frac{1}{4}$ mile long and about 40 feet deep. A sandstone boulder surmounts one of the moraine hummocks about 20 rods west of the railroad. Standing 8 feet out of the ground, it measures 15×13 feet upon the top. Most of the boulders are of sandstone, although occasional boulders of gneiss occur.

This same moraine ridge with hummocks and kettle-holes follows up Little Sandy creek for a mile and a half, being seen at first on the north side of the creek, and farther west on its south side resting against the northern slope of a hill.

Entering *Mineral township* it strikes over the hill and pursuing a course almost directly south crosses Sandy creek near Raymilton. Water-worn drift occurs in the creek.

From Raymilton southward to the line of Butler county the course of the moraine was traced by Professor Wright.

"One half mile south of Raymilton a single glaciated surface was discovered with striæ running S. 45° E.

"Two miles farther S. is a field perfectly covered with boulders from 2 to 3 feet in diameter and largely of *granite* or gneiss.

"This excessive accumulation of till and granite boulders is continuous to the S. W. corner of Mineral township and along the entire west line of Irvin township.

"Extensive ridges of gravel and till with kettle-holes were noted in the N. E. corner of Wolf Creek township, Mercer county, on the road E. of Centretown. A granite boulder was measured here, 15×6 feet, and others nearly as large."

The moraine characterized by its boulders leaves Venango county precisely at its south-western corner, on the line between Mercer and Butler counties, at an elevation of about 1400 A. T. Unlike the moraine in eastern Pennsylvania it does not represent the precise limit of glacial action, the line drawn upon the map being 2 to 3 miles west of that limit. Although no striæ have anywhere as yet been found in front of the greater accumulation here called the moraine, the occasional transported or striated boulders, and the fragmentary patches of till which constitute the *fringe*, are worthy of especial note, showing that it must be considered as a distinct feature apart from the moraine proper.

The *fringe* in Venango county consists principally of scattered fragments of sandstone, sometimes striated, and often imbedded in a sort of sandy till which forms a shallow deposit (not over 3 feet deep) upon the decomposed rock below. Rarely a small pebble of granite or gneiss is found. Throughout large tracts in the *fringe* rocks come to the surface, and no trace of drift appears. The valleys are not filled with drift, as they are back of the true moraine but are generally quite free from drift. The patches of drift that are found are almost always upon the summits of level-topped hills.

The fringe.

The following scanty data have been collected concerning the *fringe* in Venango county :

In *Plum township* upon the hill between Wallaceville and Sunville, as also north of Sunville, boulders and sharp fragments of sandstone abound, some of which are distinctly striated. Occasional azoic pebbles also occur. The numerous granite boulders seen from the road $\frac{1}{2}$ m. N. of Sunville probably mark the true moraine. A similar accumulation represents the moraine on the turnpike from Plum P. O. to Titusville. These cease suddenly $\frac{1}{2}$ m. E. of Plum P. O.; but farther east, a sandy soil occurs which, holding many sharp sandstone fragments and often large-sized sandstone boulders, forms the fringe.

In *Jackson township*, upon the hills west and north of Coopertown, sandstone boulders and rarely a small boulder of gneiss (not over 6 inches long) are seen. There is no till, and the boulders rest upon the sandstone rock below.

In *Sugar Creek township*, upon the road leading N. and S. somewhat over a mile E. of the moraine, are numerous sharp, rounded and sometimes striated fragments of sandstone, lying in a shallow sandy soil.

In *French Creek township*, upon the level plateau at the fork of roads 2 m. S. W. of Franklin, is a sandy drift resembling till and containing many rounded and striated sandstone boulders. No large azoic boulders occur.

In *Sandy Creek township* at several places upon the road

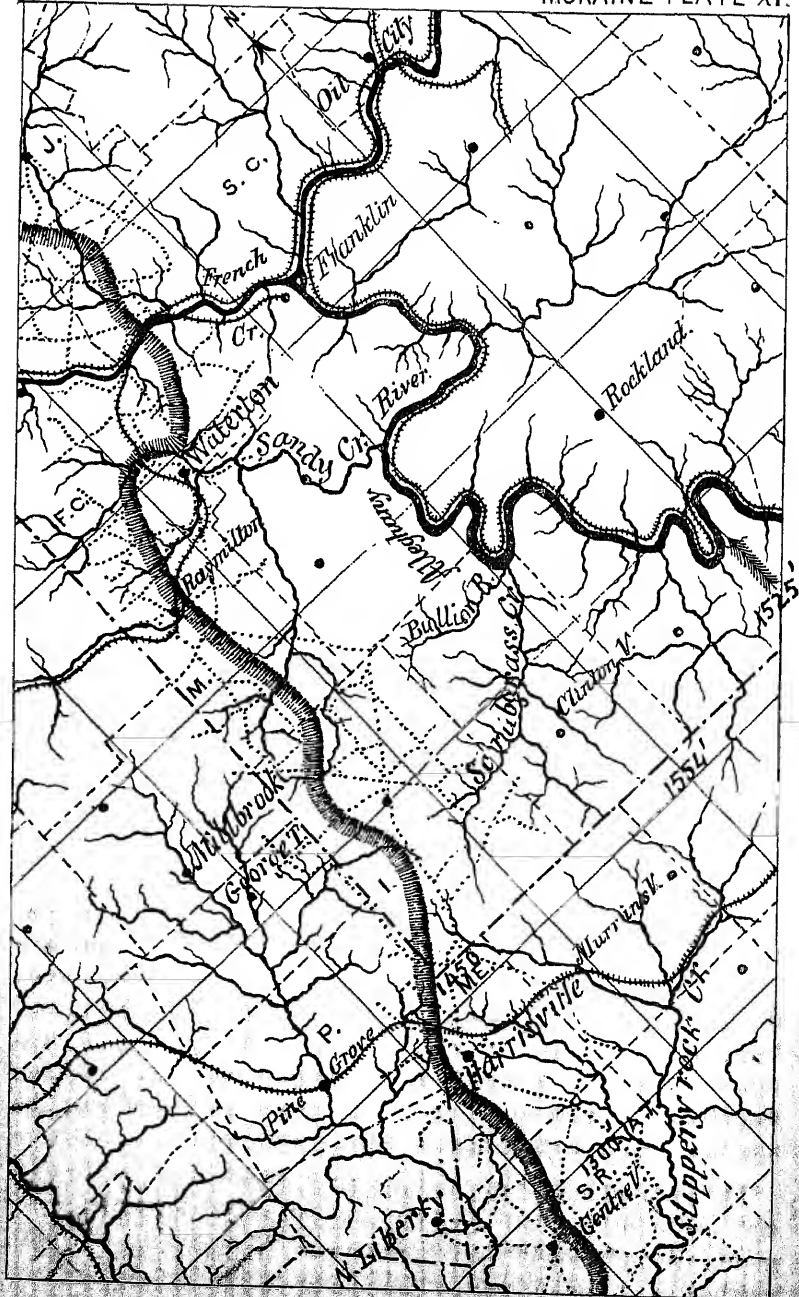
from Franklin to Harrisville, Butler county, similar sandstone boulders appear. The No. XII sandstone strata from which all of these boulders in the fringe are derived outcrop in numerous places.

In *Irwin township*, at numerous points, these sandstone boulders and fragments occur, and rarely a pebble of gneiss or granite is seen. Striated pebbles were collected nearly 2 m. E. of the moraine proper (Spec. No. —.) The numerous azoic boulders and the deposit of till which occurs $\frac{1}{2}$ m. N. of Barkeyville (Wesleyville) probably belong to the moraine proper.

Professor Wright spent a day in exploring the limits of the *fringe* in the southern part of the county and reports that "the extreme limit of glacial action is along a line running through the centre of Sandy Creek township past Dean's Mills and E. Sandy P. O. (Springville), across the N. W. corner of Clinton township; and across the S. E. portion of Irvin 1 mile S. E. of Barkeyville P. O. The indications of glaciation along this line are extremely slight. Scratched stones are found all along, with an occasional patch of till, and an occasional small granite boulder. East of it not even these were found, although frequent detours were made to a distance of a mile, and in Clinton township of 3 miles, beyond any vestige of glacial markings."

Large accumulations of stratified water-borne drift occur at different points along the Allegheny river. In the narrow gorge through which the river flows much of this drift has been swept away, and it is therefore only on plateaus bordering the river, or at sharp turns in its course, that gravel deposits remain. At the sharp bends of the river around Scrubgrass and Blacks in Rockland township, large accumulations of gravel and boulder-bearing clay occur, which rise 50 feet or more above the river. No evidences of glacial action were noticed along the Allegheny river.

The region back of the moraine is covered by a nearly continuous mantle of till in which scratched pebbles and fragments are numerous. Azoic boulders are numerous, although neither so abundant nor so large as upon the moraine.



CHAPTER XV.

In Butler and Mercer counties.

The moraine continues for several miles upon the line between Butler and Mercer counties. The glacial phenomena of the two counties will therefore be considered conjointly.

The moraine has a constant elevation of 1300-1350 A. T. in Butler county, and is distinctly seen throughout the whole of its course. It is characterized always by a great collection of large boulders, which are so numerous as to frequently render the cultivation of the fields upon which they lie impossible. Boulders of *granite* become very numerous and are often of large size.

It can be traced along the county line to a point directly west of Harrisville. A range of large granite boulders lies upon broken rock $\frac{1}{2}$ mile west of Harrisville, forming as it were, outliers of the moraine. Till appears $\frac{1}{2}$ mile farther west. At the cross roads close to the county line is a ridge of till covered by large granite boulders and bearing north-west and south-east. It appears to be a moraine ridge parallel to the motion of the ice. Its elevation is 1350 A. T. Back of the front edge of the moraine sandstone boulders abound; while on the other hand *granite is most abundant just in front of the moraine*. A possible explanation of this fact is that these latter, brought from a great distance by the *top* of the ice, have been dropped in front of the material which was pushed before the glacier by its lower strata. There are no outcrops of granite

nearer than Canada, more than 100 miles distant. This fact may be of value in an explanation of the *fringe*.

It is important also to note that the granite boulders seldom show striated surfaces.

The moraine is here of great width and lies mostly in Mercer county.

The Shenango and Allegheny R. R. passes through the moraine by some fine cuts, and its edge is readily seen from the railroad close to the county line.

A swamp lies back of the moraine, in Mercer county, being enclosed by hills of drift. A collection of rounded hills of till, dotted by numerous boulders, is found farther west, between Pine Grove and the front edge of the moraine. The distinction between the glaciated and the non-glaciated region, is distinctly and sharply shown on the Shenango and Allegheny railroad, the cuts being made through till west of the moraine, and through rock east of it.

The moraine continues southward into *Slippery Rock township*, through the centre of which it passes; and here it consists of an immense collection of boulders, often of large size, of granite and other materials. A north and south road continues upon the moraine for more than a mile and is almost impassable on account of the boulders.

This great accumulation of boulders crosses the different roads east of Centreville at a distance of from a half mile to $\frac{3}{4}$ m. east of the village. It crosses the Butler and Mercer turnpike about a $\frac{1}{2}$ mile south of the village, where the transition from the till-covered region to one where rocks every where come to the surface is sharp and readily seen. The elevation is here 1350 A. T.

Boulders of *granite* 6 feet in diameter are frequent back of the moraine.

The moraine crosses into *Worth township* close to the corner of Brady township; and forms hills and ridges of drift in the valley of Slippery Rock creek. In the north-east corner of the township it forms an irregular series of hills, covered by scratched pebbles and large boulders, well shown near a fork of roads less than a mile from the corner of Brady township.

In front of the moraine at this point and extending for a mile or more south-eastward is a magnificent kame-like accumulation of sandy *stratified drift*. A remarkable series of ridges, hummocks and interlacing hills, enclosing basin-like depressions, rises above the surface of the surrounding country at least 100 feet in height. The sides of the sandy ridges are very steep, and the whole *kame*, if such it be, is as fine as any along the whole line of the moraine. An excellent view of this accumulation is obtained from the hill above the house of Eli Taylor.

The elevation of the kame is 1200 A. T. and of the moraine 1300 A. T.

This kame-like accumulation is of especial interest in that it lies in front of the moraine and that it is not in the immediate valley of a modern creek.

South of the *kame*, another one, of almost equal interest, starts from a portion of the moraine a mile farther west and forms a steep and straight ridge two miles long. It runs along a valley, and in part along a small stream, in a direction south of east, and can be traced continuously from Mechanicsburg to within $\frac{1}{2}$ mile of West Liberty in Brady township. The road from Mechanicsburg runs either on top of the *kame* or on one side of it throughout its whole course, offering excellent opportunities for its examination. It lies at the foot of the moraine, and is a steep ridge of sandy stratified gravel, in which are no large boulders, and all the pebbles of which are water-worn. The ridge is narrow and straight at first, but in Brady township is seen to consist of several reticulated ridges. It evidently represents an ancient water course, and is worthy of more extended study.

The moraine passes through the village of Mechanicsburg (Jacksonville P. O.) being marked again by its many boulders; and then, trending still south-westward, appears in the north-west corner of Muddy Creek township near the Lawrence county line upon the "Mercer road." The transition from drift hills to the hills of carboniferous shale is sharply defined upon this road, at a point within a $\frac{1}{2}$ mile of the Lawrence county line.

In the valley of Muddy creek ($\frac{1}{2}$ m. north-eastward) sharp, kame-like ridges of water-worn drift are seen, bearing in a south-south-east direction.

South of the moraine (here 1200 A. T.) no drift was seen.

The hills in the driftless region rise 200 feet higher.

The fringe.—As in Venango county, there are traces of a narrow *fringe* at several places in Butler county. At Harrisville, and for nearly a mile east, occasional small boulders are scattered over the otherwise driftless region. The railroad cut south-east of the station shows about 2 feet of clay and “wash” on top of the shale. Farther east no drift whatever occurs. Occasional patches of clay occur in several places just in front of the moraine. Near the point where the moraine is crossed by the railroad, occasional small granite boulders are found upon a hill $\frac{1}{4}$ m. in front of the moraine, at an elevation of 1350 A. T.*

Near Mechanicsburg also a thin covering of impure clay, holding both rounded pebbles and sharp fragments, occurs in front of the moraine.

East of this narrow fringe no trace of drift was seen in Butler county. An examination was made entirely across the county to the Allegheny river, (here nearly 20 miles east of the moraine) and the soil was found to consist wholly of broken and decomposed rock, and to be perfectly free from all drift.

Numerous deposits of stratified drift along the Allegheny river were formed when that river acted as a great drainage channel for the waters of the melting ice.

*[Mr. Chance's observations on the drift of northern Butler county, made in 1878, were published in his Report V, 1879, pages 6, 7.—He distinguishes two regions of very different character, separated by a range of high land which he calls the “Muddy creek and Connoquenessing divide.” *South-east* of the divide the valleys are sharp and narrow cuts, with numerous side ravines, without well marked bottom lands. The country *north-west* of the divide has broader, smoother valleys, with fewer side ravines; banks of drift on the hill-side; and creek flats. *Erratic blocks* are of frequent occurrence even on high land, (usually in colonies, or rows, on either side of which few can be seen), and are found as far east as West Liberty in Brady township, and Centreville in Slippery Rock township; and along the creek bottoms much farther eastward. In his survey of the western townships he could find no erratics on ground much higher than 1300 A. T.—J. P. L.]

A deposit at Parker, for example, was made when the plateau which it covers was overflowed by the river. The deposit consists of a gravel similar to the red gravel at Philadelphia, composed of well-rounded pebbles, overlaid by a yellow brick-clay, holding boulders sometimes 3 feet in length. The boulders are in great part composed of sandstone and conglomerate, and are often sharp. The deposit lies upon a plateau 250 feet above the river and is quite different from the sandy river gravels in the bottom of the valley.*

In Mercer county.

In *Mercer county*, and throughout the region back of the moraine, the deep covering of till, the numerous granite boulders, the kames and ridges of sandy drift and other evidences of glaciation occur continuously to the Ohio line. The general elevation of this region is somewhat lower than that in front of the moraine. It is also important to observe that throughout this portion of the glaciated region there are evidences of the presence of great bodies of water, as well as ice; and it is probable that sub-glacial streams and lakes of large size played an important part in the formation of the drift of this region, the features of which are in several respects unlike those in Eastern Pennsylvania.

*[Mr. Chance in 1879 made a special topographical survey of the vicinity of Parker for the purpose of studying the high-level gravels on both sides of the Allegheny river, and up the valley of the Clarion river. His contour map of the neighborhood will be found in his Report on Clarion county, VV, 1880; and his description of the high-level *pre-glacial river beds* and low-level *post-glacial eroded channels*, may be found on pp. 17 to 20 of that report.

Mr. Carll has shown how the deposit of the terminal moraine, and the sheet of drift behind it, across all the water courses leading down to Lake Erie, changed the drainage of Northern Pennsylvania and Southern New York, and converted an originally insignificant creek into the present great Allegheny river, which commenced its career by a violent deepening of what was thenceforth to be the main water-way of the region. Mr. Chance's map shows the cut-off at Parker which the new river made across two of the horse-shoe bends of the old channel.

On page 21 of the same Report (VV) may be found a small sketch map of a similar deep cut-off, at Callensburg in Clarion county, made by the Clarion river, in the process of lowering its own bed to manage its new relations with the Allegheny river.—J. P. L.]

Large deposits of a boulder-bearing clayey drift, of a pale color, fill up the valleys, often to a great depth. Deposits of this character may be seen abundantly in the western part of Mercer county. The valley of the Shenango river, for example, is so filled up by this clayey drift as to cover up all rock outcrops and to be almost level with the surrounding hills. The boulders are generally rounded, and are of all sizes. Boulders of red granite, containing hornblende, form conspicuous objects in the fields, and are often over 6 feet in length. They are known throughout this region as "hard-heads." Railroad cuts through this drift show that it is a compact and clay-like deposit, containing very few boulders, and at least 30 feet in depth.

A very interesting *rounded hill of compact till*, near Sharpsville (3 m. east of the Ohio line) at an elevation of 950 A. T. or 375 above Lake Erie, is finely exposed by a cut made by the Erie and Pittsburgh R. R. The railroad cut shows that the till consists of two portions, an *upper* and a *lower* till, which are sharply defined by a dividing line. The upper till, some six feet deep, is yellow; while the lower till of unknown depth is of a blue color. The lower till is far more compact than the upper. It is so compact that it is difficult to cut it or extract stones from it, and when cut away remains standing in a vertical wall like a rock. Its pebbles and boulders are typically shaped by ice action. Composed of every kind of rock, often finely striated, sometimes jagged at the ends, and smoothed off at the sides, sometimes in irregular fragments, and sometimes completely rounded, varying in size from the smallest pebble to huge blocks of many tons' weight, they present a typical example of Glacial Drift. Both the *upper* and the *lower till* are stratified on a large scale. In both of them there are nearly horizontal lines of boulders, as though the whole mass had been pushed and packed by a heavy movement in one direction. This *imperfect stratification* appears to be due to ice action alone, and it looks as though the whole deposit had been formed under the glacier which rode over it and packed it down. The shape of the hill is oval, with its longer axis

apparently in the direction of the movement of the glacier.

A school-house stands on top of the hill; and other hills of similar shape are seen in the vicinity.

The *upper till* appears to be the result of the alteration of the *lower till* by atmospheric agencies. Although the line of demarkation between the two is distinct, there is no difference in composition, and no proof of a different origin. Boulders of red granite and of hornblendic gneiss occur in both.

Other hills and ridges of till occur in different parts of Mercer county and perhaps represent portions of one or more *moraines of recession*.

The drift deposits back of the moraine form in some places much greater accumulations than at the terminal moraine; and it is probable, therefore, that the terminal moraine here traced, while indicating the farthest southward extension of ice, does not represent its longest halt.

The *striae* in Mercer county, as noted by Prof. I. C. White, have a general direction S. 45° E. at right angles to the moraine.*

* [Prof. White furnishes the following data in his Report on Mercer county, QQQ, 1880:

Page 90.—*Striae* nearly south-east on a smooth-planed surface of sandstone, capping a high knob, one mile east of Middlesex; 130' above level of Sharon coal bed—1110' A. T.

Page 103.—*Striae* on Hoagland's Knob (Homewood sandstone) in Hickory township; nearly 1300' A. T.

Page 122.—*Striae and grooves*, bearing nearly south, on an ice-polished surface of Sharon conglomerate, at Whittaker's falls, Hickory township.

Page 166.—*Striae* frequent along the valley of the Little Shenango, and parallel to its sides, i. e. nearly east and west, in Lake township.

Page 189.—Deep *striae*, on polished layers of the Conglomerate, along the Little Shenango valley road, in Otter Creek township, on McNight's land; general course south-east, parallel to the creek.

Page 189.—*Striae* in all parts of Hempfield township, wherever the rocks are uncovered from soil—for example:

Two sets of striae, one south-east, the other (and larger) south south-east (some of them 2' deep and 8" broad), on a high knob, just north of Salem Presbyterian church.

Two sets of striae, one south-east, the other (stronger and deeper) south 20° east, on the Conglomerate cap of a very high knob in the south-west corner of the township.—J. P. L.]

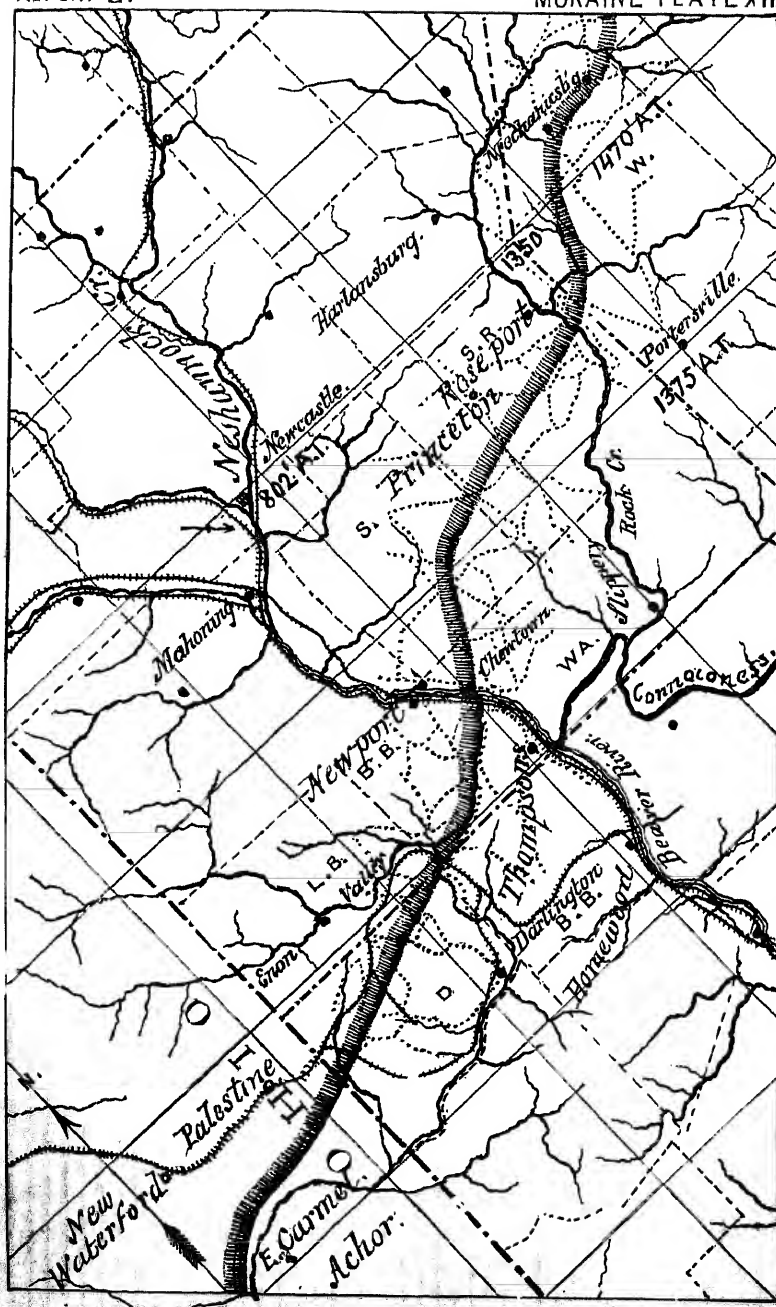
The swamps and lakes which are found in several portions of the county are due to the obstruction of streams by glacial débris.

Of the most noticeable drift deposits mention should be made of characteristic glacial hills of till at West Middlesex, Shenango township. These form a line of drift hills several miles long which can be seen from the line of the Erie and Pittsburgh R. R. Steep, rounded hills, formed of yellow till and covered with boulders of sandstone, granite, gneiss and other materials (many of which are striated) and containing also sharp fragments of local rock, rise high above the river, and, enclosing shallow depressions, have a typical moraine topography. A level plain of stratified drift covers the base of these drift hills in the river valley. (Spec. of granite pebble No. — from till at West Middlesex.) These accumulations come to an end about two miles north of the Lawrence county line and are possibly connected with the oval hill at Sharpsville.

Numerous hills of till are exposed by the R. R. cuts south and east of Mercer. The till is 30-40 feet deep, and forms a continuous mantle. On the line of the Shenango and Allegheny R. R. the till is continuous, and often finely exposed from Mercer to the moraine near Harrisville in Butler county; from that point eastward, to the terminus of the road at Coalville, the cuts are through rock, and no trace of drift is seen.

The numerous deposits of stratified drift throughout the county are well worthy of study. One of the most interesting of these is a *kame-like ridge*, which, bearing in a south-south-east direction runs along the centre of the broad drift-filled valley near Pardoe, Findley township. It consists of a series of reticulated ridges of hummocky contours and composed of stratified sand and gravel. A sluggish stream now flows along the valley. The elevation at this point is 1200 feet above the sea. As seen in a transverse section these ridges consist within of deposits of stratified sand, whose layers have often an *anticlinal structure*, while coarser gravel forms the outer part of the kame.

In one place, where two "reticulated ridges" join, may be seen two deposits of sand side by side, each having an anticlinal structure, but both united by a covering of gravel to form a single ridge, thus forming a *double kame*. (See Fig. 5, page-plate 18, page 150.)



CHAPTER XVI.

In Lawrence county.

The boundary of glaciation appears on the county line, and re-crosses Slippery Rock creek a mile above Kennedy's lower mill, and about one mile south-east of Rose Point. Here, upon the east bank of the deep gorge through which the creek flows, there is a noteworthy collection of boulders of gneiss and granite many of them four feet in diameter. A number of these are composed of massive *labradorite syenite* (?) (Spec. No. --.) The deposit of till comes down to within a few rods, completely enveloping the country to the north-west. The elevation of this point is about 1200 A. T. while hills two miles to the south-east rise 150 feet higher, to about 1350 A. T.

Two miles farther west, and about two miles south-east of Princeton, the margin of the glacier, passing near Hope Furnace, is marked by frequent *granite* boulders (from 3-4 feet in diameter) and by numbers of immense boulders of sub-carboniferous sandstone. One of these, standing five feet out of the ground, measured 10×15 feet, and others were nearly as large.

Granite is now much more abundant than gneiss.

Three miles west south-west of here the moraine crosses the township line into Shenango township, at a point upon the new Pittsburgh turnpike about 6 miles south-east of New Castle, near a Baptist church. From New Castle south-

(193 Z.)

eastward along the pike to a point within 30 rods of the Baptist church *till* is continuous, and to all appearances deep, the boulders of which become larger and more numerous as the edge of the drift is approached. South-east of this a slaty soil appears everywhere upon the surface, and rocks, heretofore exposed only in the steep sides of ravines where the drift has been cut away, are now seen at every cutting.

From here to the place formerly known as Shenango P. O. the accumulation of boulders can be readily traced, lying at an elevation of 1300-1350 feet above the sea. The boulders are principally of sandstone, one of which was between 8 and 9 feet in diameter.

Near the boundary of Wayne and Shenango townships, about 1 mile north-east of Chewtown, the moraine is recognized by numerous boulders perched upon hills rising 350 or 400 feet above the Beaver river. In some places one could almost jump from boulder to boulder. Slate hills adjoin the moraine on the south-west.

The Beaver river is crossed by the moraine at Chewtown, 8 miles south of New Castle, and is here filled with immense accumulations of stratified drift, several miles in length. Chewtown stands upon a high and broad *terrace* more than 150 feet deep, which forms a level plain at its southern terminus, but which develops northward into ridges and conical hills enclosing large *kettle-holes* and having all the typical features of a glacial deposit. This conspicuous accumulation extends for nearly 2 miles up the river, and is heaped up into still higher knolls and ridges as the river is ascended. It passes into *till* upon the higher ground on each side of the river. While the water issuing from under the glacier in this river valley has stratified the materials of the moraine and, with the aid of ice, has heaped up the sand and gravel into the peculiar knolls and ridges so characteristic of a glaciated region, no evidence appears that the glacier extended any tongue of ice down the river. There is no sign of drift deposits in the valley of the Beaver south of the moraine other than those formed by the action of water.

West of the river in Big Beaver township there is a deep covering of *till* which, heaped up into knobs and ridges, enclosing basin-shaped depressions covered with numerous large boulders of Canadian *granite* and *gneiss*, forms a large development of the moraine here several miles in width. The edge of this great accumulation of till extends to the south-west corner of this township, where it crosses into Beaver county.

A deposit of *stratified drift* lying in ridges and hummocks fills up the valley of Little Beaver creek at this point.

The *fringe* of boulders in front of the moraine is more prominently developed in Lawrence county than along the line of the moraine described in the preceding chapters.

This circumstance was sometimes a source of confusion in tracing the precise limit of the moraine proper.

Boulders of granite, often of large size, are perched upon the tops of hills in front of the moraine, and, as far as three miles in advance of it.

Upon the summits of hills south-east of the moraine in Slippery Rock township occasional large boulders of granite, sometimes six feet in length, were found 450 feet above the river (1250 A. T.)

Boulders of granite three feet in diameter occur on top of a hill one half mile south of the moraine, 400 feet above the river in Wayne township east of Chewtown.

In Big Beaver township, west of Clinton, scattered granite boulders without any accompanying till were found upon the hill-tops south of the moraine.

The boulders of this *fringe* (which is still more extensively developed in Beaver county) are almost exclusively composed of *Canadian granite*.

The glaciated region back of the moraine is much more deeply and continuously covered with *till* than is the corresponding region in eastern Pennsylvania.

In eastern Pennsylvania the glacier *descended*, from a higher level, to a region traversed by numerous sharp mountain chains at right angles to its course.

In western Pennsylvania the glacier *ascended*, from the depression of Lake Erie, into a rolling country in which there are no mountain chains, the upward slope of which south-eastward is a gradual one.

In the first case the till was combed out of the glacier by the mountain chains obstructing its onward flow.

In the second case the unimpeded southward movement of the ice to its line of constant melting carried along a continuous supply of drift material, to be dropped evenly upon the region where the glacier was always melting while still advancing.

Among the more prominent accumulations of *till* north of the moraine, in Lawrence, may be mentioned:—the ridges and conical hills covered by boulders which occur at Mount Jackson in North Beaver township, and from that place southward to the limit of the moraine;—similar accumulations in Slippery Rock township, five miles east of New Castle;—and a series of moraine-like hills upon the Shenango river near Harbor Bridge.

These and similar deposits may belong to *moraines of recession* hereafter to be traced across the State.

As elsewhere throughout the glaciated region, *till* is always most abundant on that side of a hill towards which the glacier has flowed.

The north-west side of hills is therefore most deeply covered by drift in this county.

Glacial striæ bearing S. 45° E. were seen one half mile north-west of Newcastle, on the road to Edinburg, 175 feet above the Shenango river (975 A. T.)

The deposits of *stratified drift* found in every valley back of the moraine are finely developed, in kame-like ridges, at a number of places upon the Beaver and Shenango rivers, and are similar to those already described elsewhere. They form a series of hummocks and kettle-holes along the Beaver river, between Mahoning and Newport, which merge into *till* upon higher ground. A fine sandy *kame*, 100 feet high, and formed of several ridges, appears upon the Shenango north of Newcastle. Other kame-like hills of char-

acteristic topography occur two and a half miles north-west of Princeton, at about 1200 A. T.

Near here is a *glacial pond* with no outlet.

A distinction is to be observed between those deposits of stratified drift whose present contours were moulded under or in the near proximity of the glacier and those formed by erosion in post-glacial times. *Kames* belong to the first kind of deposits. *Terraces* and *crag-and-tail* deposits fall into the second category.

The lower portion of the Neshanock creek, near the northern county line, flows through a narrow gorge, with high vertical walls, and generally swept clean of drift; but on the down-stream side of projecting crags of rock a coarsely stratified deposit of drift may be observed, in several places, rising 50 feet or more above the river. These are specimens of *crag-and-tail deposits*. They are evidently remnants of a once large deposit which the projecting rocks have preserved from erosion. (See Fig. 6, page-plate 18, page 150.

[NOTE.—Mr. White, in his Report on Lawrence county, QQ, (published in 1878) says, on page 7, that he recognized the glacial drift as extending southward at least as far as Wampum; because he saw drift 30 feet deep exposed at a limestone quarry 275 feet above the Beaver river at Wampum. Mr. Lewis confirms this observation by making his line of the terminal moraine cross the Beaver at Wampum.

Near Mt. Jackson, west of the mouth of the Mahoning, he reports wells sunk 40 feet in drift without reaching mother rock, 400 feet above the level of the Mahoning water, (page 8.)

On Slippery Rock creek, he reports that the drift seemed to reach no further south than Kennedy's upper mill, and this also Mr. Lewis confirms by lining the terminal moraine about a mile south of Rose Point.

In 1877 Mr. White did not recognize drift on the high land east of the Beaver beyond three miles south of Newcastle, so that he supposed the south limit of drift to run nearly due west from Kennedy's mill on Slippery rock to the mouth of Big run.

But the accumulation of boulders 1 m. N. E. of Chewtown (opposite Wampum) perched on hill tops 350 to 400 feet above the Beaver waters has induced Mr. Lewis to draw a gentler curve.

In his survey of Beaver county in 1877, and of Lawrence county in 1878, Mr. White paid particular attention to the erratic boulders scattered over the region, and perched upon the highest lands. But he was unable to connect them with the Drift, and consequently adopted the iceberg theory to account for their distribution. See Report QQ, 1879, page 9. In this way he explained to himself their apparently uniform situation on the upper surface of the Drift; and also, their occurrence "much further south than Drift is known

to extend" (page 10). Mr. Lewis recognizes in the latter class of facts his *fringe*.

But Mr. White in the course of his survey of Mercer county in 1879, learned much more concerning the constitution of the drift than appeared in Lawrence and Beaver counties. A great number of shafts sunk to mine the Sharon coal bed, went through from 50 to 100 feet of drift, and scarcely one of them failed to encounter one or more erratic boulders enveloped in the Drift, and precisely similar to those lying on the present surface of the ground. The iceberg theory was of course abandoned by him and another adopted, which he described in his Report QQ, 1880, page 16.—J. P. L.]

CHAPTER XVII.

In Beaver county.

The deposit of till and boulders constituting the moraine appears to have its southern limit in the north-west corner of Big Beaver township, Beaver county, about one mile north of New Galilee. From this point it passes west-south-west through Darlington township, keeping upon the hills about a mile south of the Pittsburgh, Fort Wayne and Chicago R. R. and nearly parallel to it, until at a point two miles south of the northern line of the county (thirteen miles north of the Ohio river) it crosses into Ohio.

It has here an elevation of 1150 A. T. and 450 feet above the Ohio river at the State line.

Everywhere boulders of *red granite* are common upon the moraine; and in fact most of the large boulders are composed of this material.

The details of the moraine are as follows:

An accumulation of till in ridges and rounded hills covered with granite boulders forms the moraine near the line between Lawrence and Beaver counties, just north of the house of J. Dillon, in Big Beaver township. Outcrops of slate occur immediately in front of the moraine, sharply defining the limit of the till. (Specimen of granite boulders, &c., No. —.)

A mile and a half farther west, near the line of Darlington township, at the house of D. C. Forney, a region covered by till and dotted with granite boulders suddenly ceases; and a shaly soil, formed by the underlying rock, continues from here southward.

Modified drift and a boulder-bearing clay occur in the valley at New Galilee, south of the moraine; and among the boulders one of *staurolite schist* (Spec. No. —) was found at this spot.

Boulders of red granite are very common throughout Darlington township upon the moraine, (Spec. No. —.)

The moraine, keeping, as stated, about a mile south of the P. Ft. W. and C. R. R. may be seen upon several cross-roads, and forms characteristic rounded hills of till upon the Ohio line two miles north of Little Beaver creek.

The fringe attains its fullest development in Beaver county, traces of it being seen as much as 5 miles south of the moraine proper. Upon a number of hills in Big Beaver, Darlington and South Beaver townships, at elevations of 200 feet above the Little Beaver creek, or 1175 feet above the sea (being thus about the elevation of the moraine proper) there may be found boulders of red and white granite, gneiss and other rocks, many of them striated and often several feet in diameter. These boulders, most of which are of granite, generally lie upon the rock in place, or upon the soil made of it; but occasionally they are accompanied by a shallow deposit of clayey drift resembling till. It is only upon the summits of the hills that the boulders occur; and in no case are there any hills of till or wide spread deposits of stratified drift such as characterize the moraine and the glaciated region north of it.

The most southern extension of the fringe was observed upon hills in the south-west corner of South Beaver township 5 miles south of the moraine; and an examination of the region between here and the Ohio river failed to find them farther south.

The Fringe.

In reviewing all the facts regarding the fringe presented in the foregoing pages it will be noticed

- (1.) that it is confined to the western portion of the State;
- (2.) that it increases in width from Warren county to Beaver, where its maximum width of 5 miles is attained;
- (3.) that it is in great part composed at first (in Warren county) of sharp sandstone fragments;
- (4.) that it contains more and more azoic boulders going south, until in Beaver county its most abundant and prominent boulders are of granite; and
- (5.) that its elevation throughout is about that of the moraine back of it, although it is sometimes somewhat higher.

No striae have as yet been found in the narrow region covered by the *fringe*. The hill tops bearing the boulders of the fringe are in all respects similar to those south of the limit of all drift and bear no evidence of glacial erosion.

Nor is the material of the *fringe* confined to any particular elevation occurring irregularly at different heights.

These facts, puzzling when first observed, and at first causing some trouble in determining the line of the accumulations of till, boulders and scratched stones designated the *the moraine*, came afterwards to be commonly looked for as invariable phenomena. It is possible that traces of this fringe might be detected in Eastern Pennsylvania and in New Jersey. In fact occasional transported boulders do occur upon several hill-tops just in front of the moraine in the vicinity of the Susquehanna and Delaware rivers and in New Jersey, which I find it difficult to explain upon any theory of a flood, and which may be of like origin with the fringe as developed farther west.

Facts observed by other geologists in more western States and published since this report was written, confirm my impression that this fringe is destined to play an important part in glacial geology.

It has become known that, west of central Ohio, the edge of the glaciated area is not marked by any true moraine,

but that the true moraine lies some miles back from that edge.

It has been recently pointed out that the fringe widens greatly towards the west, assuming its greatest extension in Dakota.

Through southern Indiana and Illinois, and in the region bordering the Missouri river in the west, there are occasional transported boulders, regarded as indicating glaciation; but on the other hand, no drift ridges, no glacial striæ and no signs of glacial erosion are reported, and the boulders come to an end with no sign of a moraine bounding them.

Professor T. C. Chamberlin informs me that in Dakota, west of the Missouri river, there occur clusters of boulders (more frequent upon the hill-tops than elsewhere, and generally unaccompanied by till, gravel or sand,) which are the sole representatives of the drift. These boulders are generally granitic, having been transported from the Laurentian region 300-500 miles away. They are sparsely scattered at different elevations, sometimes on summits and sometimes on slopes, and lie directly upon the underlying mother rocks.

No striations have been observed in that region; nor does the topography show any sign of the influence of glaciation.

Similar observations have been made at other points along the margin of the drift; showing that the fringe, so narrow in Pennsylvania, widens out to 60 or 70 miles in the west, and becomes a feature of great importance.

CHAPTER XVIII.

In Ohio, Kentucky, and Indiana.

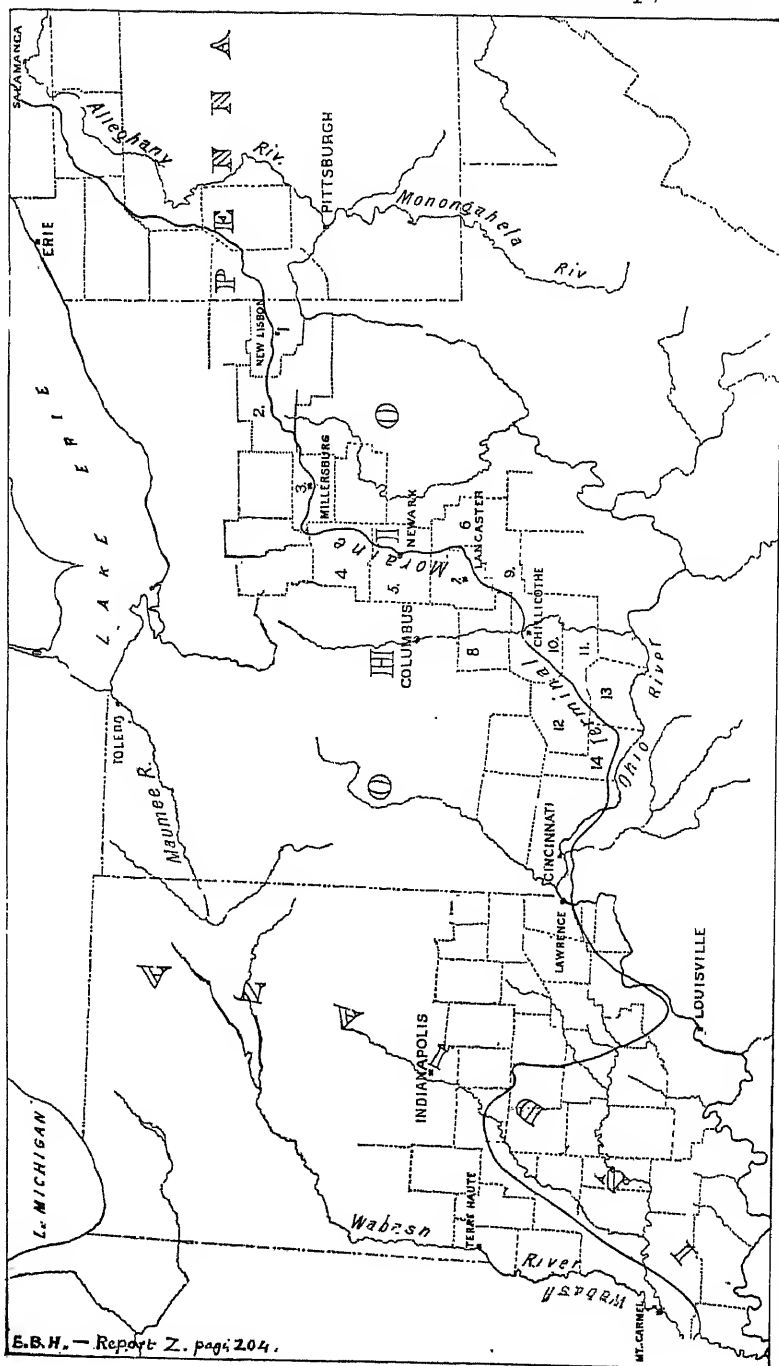
[The Rev. G. F. Wright, formerly of Andover, Mass., now of Oberlin college, Ohio, has recently given to the public a detailed description of his survey of the Terminal moraine in its course westward from the Pennsylvania-Ohio State line.*

A few extracts from a lecture on the Glacial Period in America prefixed to the memoir will explain sufficiently the object of the survey.

"When, ten years ago, I began my investigations concerning the Kames of the Merrimac valley, in Eastern Massachusetts, I little thought to what it would lead ; and, after having traced the boundary of the glaciated area from the Atlantic Ocean to the southern part of Illinois, I am equally in doubt as to what the future has in store in this most interesting line of exploration." (Preface.)

"It was my privilege, several years ago, in a more definite manner than had been done before, to call public attention to the nature of these accumulations in Southern New England. I was enabled to do this through information furnished me by Mr. Clarence King, who gave me the facts in 1876, to be published in a communication to the Boston Society of Natural History upon the glacial Phenomena of Eastern Massachusetts. (See proceedings Vol. 19, p. 62, 1877.) When this clue had once been furnished, it was a short matter to trace the line along the southern shore of

*The memoir is published by the Western Reserve Historical Society at Cleveland, O., and funds for making the survey were provided by friends of the Society, named by Professor Wright in his acknowledgment.



New England and through Long Island. This work was done by Mr. Warren Upham."

"By independent investigations Professors Cook and Smock, of the New Jersey Geological Survey, discovered the significance of certain glacial accumulations in that State, and a little later published (Report on the geology of New Jersey for 1878) a map of the Terminal Moraine in New Jersey." (page 11.)

"South of New England the boundary line (or moraine) is marked by a line of hills from 50 to 250 feet in height and from two to three miles wide. These hills are composed of loose material thrown together in irregular hummocks and ridges, with many enclosed depressions, to which there are no outlets, called 'kettle holes.' Many large boulders, brought from a long distance, are found scattered over these hummocks." (page 20.)

"In Columbiana county, Ohio, and in the eastern part of Stark county, the accumulation is somewhat less marked in quantity than further east, but is the same in quality. The apparent diminution in quantity may arise from its having been spread over a wider base. But, near the western part of Columbiana county, at New Alexandria, two or three miles back from the very extreme limit of glacial signs, the familiar knobs and kettle holes of the moraine are distinctly marked and that upon the very height of the land A mile or two west of Canton, in Stark county, the accumulations are upon a scale equal to anything in New England. The northern part of Holmes county is covered with till which is everywhere of great depth At the old village of Danville near by upon a neighboring hill, wells are reported as descending more than a hundred feet without reaching the bottom of the till The reservoir at Thornville seems to be a great kettle hole The accumulation at Adelphi in the north-east corner of Ross county is more than 200 feet, and continues at this height for many miles westward In Boone county, Kentucky, the accumulation of glacial material extends several miles south of the Ohio river and many feet in depth, and is here at an elevation of more than 500 feet above the river. . . .

"At every step along the line granite boulders of every size and shape and complexion are to be found. The two largest measured were one in Columbiana county near Han-overtown which is 13 feet long by 11 wide, and which stands 8 feet out of the ground; and another near Lancaster, in Fairfield county, which is 18 feet long, 12 feet wide, and stands 6 feet out of the ground. These are granite boulders whose native ledges are in Canada, far to the north of Lake Erie." (p. 22.)

"In Campbell and Boone counties, Kentucky, the ice crossed and projected several miles south of the Ohio river. From the elevations at which these accumulations occur it is certain that the ice barrier at Cincinnati must have been at least 600 feet. This would set the water of the Ohio beyond Pittsburgh, far up into the Allegheny and Monongahela rivers, submerging Pittsburgh itself to a depth of about 300 feet Long bays must have stretched up on the north through all the valleys [of Ohio] to the ice front. Thus the glacier in south-eastern Ohio would for awhile seem to terminate in an archipelago." (page 28.)*

The following pages are printed *verbatim* from pages 35 to 76 of Mr. Wright's memoir.—J. P. L.]

I. COLUMBIANA COUNTY.

The boundary line of the glaciated region as it enters Ohio from Pennsylvania is not so distinctly marked by large accumulations of till as in many other places; so that it might create misapprehension to speak of a "terminal moraine" in Columbiana county. Still the boundary is well defined, and on penetrating the glaciated region a few miles, the accumulation of till is extensive. As we approached the Ohio line through the western counties of Pennsylvania, it was observed that what we have called "the fringe" became more extensive than in the eastern part of the State, that is, scattered granitic boulders and occasional accumulations of till are found in some places five or six miles south of

* For a discussion of the amount of erosion of the country as a datum for estimating the date of the glacial period, Mr. Wright refers to chapter VI of his "Studies in Science and Religion," Andover, W. F. Draper, 1882.

the line bounding the continuous accumulation of till which envelops the larger part of the glaciated region. This peculiarity continues through Columbiana county, from east to west, and as far as Canton in Stark county.

For example : The accumulations of till worthy of being called a "terminal moraine" and of being reckoned as a continuation of that which marks the boundary of the glaciated region in New Jersey and Pennsylvania, enters Ohio at Palestine, Columbiana county, near the boundary of Unity and Middleton townships. The wagon road from Darlington to Palestine enters a great accumulation of till, near John Hartshorn's, about one half mile south of the Pittsburgh, Ft. Wayne and Chicago R. R., and one mile east of Palestine. Here, upon the land of the State Line Coal Works, upon a hill sloping to the north, is a striking collection of granitic boulders, one which measures $9 \times 6 \times 4$ feet. In the valley to the north, through which the railroad runs, the accumulations of drift show the modifying action of the glacial currents which characterized the closing stages of the glacial period. The broken ridges and knobs of gravel, alternating with shallow kettle-holes, remind one of the kames in New England. Palestine is built upon such a formation. A large granitic boulder was here observed, in a freshly dug grave, five feet below the surface. A well was reported as penetrating till for fifty feet without striking the bed-rock. Three quarters of a mile south-west from Palestine, a cut shows twenty feet of till; but boulders of granite and scratched stones with an occasional slight deposit of till, were found several miles further south, on the summits of the hills. We walked from Smith's Ferry, on the Ohio river, northward over the hills, to a point on the State line east of Achor, in Middleton township, without finding any signs of glaciation. Here granitic boulders began to appear near Danison's coal bank. On the summit of the hill one half mile west of Achor, and about 200 feet higher than the bed of Little Beaver creek, is a granitic boulder $5 \times 3 \times 3$ feet. From this point northward to the moraine at Palestine, these scattered but un-

mistakable evidences of the presence of the glacier ice are found upon all the hill-tops.

After this description of the fringe, and its relation to the moraine, we may pass more rapidly over the subject. The boundary of the fringe runs south-westward from Achor to Clarkson post-office, thence to the south-eastern corner of Elk Run township; thence westward along the southern line of this township to the south-eastern corner of Centre township; thence it bears northerly, striking the line of Hanover township two miles north-east of Dunganon, thence westerly and bearing a little south of Hanover township, passing one half mile south of Hanoverton post-office, continuing west to Bayard. At Rochester there is an extensive kame-like deposit filling the valley, which is here about one half mile wide, in which are numerous granitic pebbles from three to six inches in diameter. One of these gravel ridges, running north by south, measured a little over 30 feet in height, with a slope of 20° . This cluster of kames is evidently due to the glacial floods pouring down the two branches of Big Sandy creek, which here unite. The accumulations of gravel in the valley of Big Sandy creek gradually diminish in amount and in coarseness from here on to Minerva, in Stark county. The ice all along here filled the valley and rose to the summit of the hills on the south. One boulder was found in the north-western corner of Augusta township, Carroll county, but an extensive *detour* of several miles to the south failed to discover any other signs of glaciation in that county. On returning to Bayard, till was found one half mile south-west, rising upon the hills south of the valley to a height of 50 or 60 feet. One half mile north-west of Bayard is a terrace 31 feet above the present flood-plain, enclosing a shallow but extensive kettle hole between it and the hills to the north.

Retracing now our steps we find that from three to five miles north of the edge of this fringe there is a marked increase in the accumulation of till showing itself at East Palestine and near East Carmel post-office. Thence across Elk Run township through Elkton to New Lisbon. The

north-east part of Centre township is completely enveloped with till of an unknown depth. Three miles from New Lisbon and a quarter of a mile west, on the road to Tee-garden, is a boulder of gneiss $8\frac{1}{2} \times 6\frac{1}{2}$ feet, 4 feet out of ground. At and below New Lisbon, in the valley of the Middle Fork of Beaver, are the extensive accumulations of pebbles and coarse gravel which everywhere mark the streams as they issue from the line marking the terminal moraine. The terrace at New Lisbon shows no distinct stratification, and contains numerous pebbles from 10 to 15 inches in diameter, and at the railroad station is 36 feet above the river. Upon the north side, this extends for one mile down the stream. Still further down, similar terraces appear at intervals nearly to Elkton. The gravel in all these terraces is mined for kidney ore.

From New Lisbon west, the moraine runs through the northern part of Sections 23, 22, 21, 20, and 19 in Centre township. In Hanover township it passes directly west, through the northern part of Sections 24, 23, 22, 21, 20, and 19. Two and a half miles north-east of Hanoverton, on the farm of Mr. Kinnely, the moraine is well developed, displaying its characteristic hummocks and kettle-holes upon the summit of the country. Large boulders are here very numerous, many from 3 to 5 feet in diameter. A mile or two farther north, near the State road, on the farm of Francis Blythe, is a granitic boulder 13×11 feet, 8 feet out of ground. Till is here certainly 16 feet deep, but how much more we could not ascertain.

Through West township the moraine bears slightly north, passing through the village of New Alexandria, which is situated upon a height of land, and surrounded by hummocks and kettle-holes of moderate size. Wells are reported 27 feet and 50 feet without striking rock. This continues through New Chambersburg, where wells were reported on the farm of Henry Bowers as going 27 feet without striking rock, the lower 6 feet in gravel and sand.

2. STARK COUNTY.

The boundary line of the fringe in Stark county runs from Bayard north-west through Paris and Osnaburg townships, passing through the villages of Robertsville and Osnaburg. Boulders of large size are found a little back from this line in the eastern part of Paris township, some of them measuring between 7 and 8 feet. Two and a half miles south-east of Paris post-office the last indications of ice-action are a few boulders in Section 15, one measuring $4 \times 3 \times 2$ feet. West of Osnaburg the fringe becomes merged with the main accumulation.

The moraine proper passes through the northern sections of Paris and Osnaburg townships. One mile east of Paris post-office granitic boulders are numerous, and cuts in the till show it to be at least 10 feet deep upon the hills, and probably 20 feet. Three quarters of a mile south-west of Paris, in the valley of Black Creek, the terrace of water-worn material is 15 feet above the stream, which is here small. The terraces are partially ridged, and contain shallow kettle-holes. On the farm of D. P. Sell, Section 6 of Paris township, wells are reported 30 feet deep, the first 8 feet being yellow till, the remaining 22 feet blue till. Another, 20 feet deep, ended in quicksand. This is on the high lands. Till completely envelops the south-eastern corner of Nimishillin and the north-eastern of Osnaburg townships. Kettle-holes are also apparent on the farm of H. Miller. In Section 2, Osnaburg township, on the farm of G. Hennigs, wells are reported 18, 20, and 26 feet, all in till. On a little higher land, in the south-west corner of Section 2, J. Anthony reported a well 14 feet through till. Till of unknown depth completely envelops the region for three miles south of Louisville post-office. There are kame-like ridges in Section 3, Osnaburg township, in a shallow valley along a branch of East Nimishillin creek. The whole appearance of the country is as if filled up with till. Till continues on the road from Louisville to Osnaburg, where it suddenly ceases, at the corner of the diagonal road running to Robertsville. From Osnaburg south-west, for three miles, thence north-west three miles towards Canton, not a

pebble or boulder was discovered. Much of the way the road is on high land, deep valleys opening southward—it being on the water-shed between Nimishillin and Big Sandy. On crossing a small branch of the Nimishillin two and a half miles south-east of Canton, in the south-western corner of Section 14 in Canton township, we struck suddenly into till on the north bank. From this point to Canton city till is continuous and granitic boulders are abundant. The depth of the till is unknown, but at various places cuts show it to be at least several feet deep. Sections 11 and 12, north of the Osnaburg road, are completely enveloped with till. A few rods north-east of the cemetery, about one mile east of Canton, are shallow kettle-holes in till. Upon the east branch of the Nimishillin the terrace facing the stream and a short distance back is 41 feet above the flood-plain. This contains many pebbles 16 inches and more in diameter. All are well rounded, and many are of local material. The cemetery, 20 rods farther east, is 16 feet higher, and is upon till. On the west side of the west branch of the Nimishillin the terrace rises in successive stages more than 80 feet, and its surface is very uneven. A mile and a half south of the city, below the junction of the two branches, there are two well-marked terraces, the first of which is much the broader, and is 38 feet above the bed of the stream. The upper terrace, on the east side, is 36 feet higher, or 74 feet above the stream. The pebbles in the upper terrace were a mixture of granite and local rock, some of them a foot or more in diameter. One granitic pebble was more than 2 feet in diameter. The terrace on the west bank, near the Starr Mills, was by measurement 5 feet higher than that on the east.

A remarkable cluster of kame-like ridges covers the north-western portion of Canton township and the north-eastern of Perry, extending an unknown distance to the north. Meyer's Lake and Sippo Lake are enormous kettle-holes, and the whole region has much the appearance of Plymouth township in Massachusetts. Upon the south this kame-like belt is called Buck Ridge, and comes to a sudden termination near the crossing of the Fort Wayne

and Chicago railroad, two miles south-west of Canton city. Here an excellent section is made by the railroad. The kame rises 85 feet above the railroad, is coarsely stratified in places, contains many granitic pebbles, (one of which measured $55 \times 46 \times 18$ inches,) and was $21\frac{1}{2}$ feet higher than the railroad. There were large spaces in which no stratification appeared. There were pebbles upon the summit from 2 to 5 inches in diameter. The section exposed shows a base of 570 feet, with an altitude of 85 feet. The slope upon the east side varies from 18° to 25° ; on the west side it is a little more gentle. (See cut in Geological Survey Ohio, Vol. II, p. 44.) An extensive sandy plain, full of gentle swells and ridges, stretches to the westward, while the space towards Canton is occupied by the more nearly level terrace. About 150 yards north of this section is a dry kettle-hole 25 feet deep, containing a granitic boulder $51 \times 25 \times 31$ inches. Another dry kettle-hole near by is about 300 feet long, 200 feet wide, and 40 feet deep, with sides sloping inward 24° . The rims of these kettle-holes are at the summit of the kame.

From my experience elsewhere, I should expect to be able to trace a series of kames northward from this point, and find it enclosing the lakes in the southern part of Summit county, and particularly abundant south of Akron.

From Canton westward the fringe pretty much disappears, and the moraine bears rapidly southward, running across the south-eastern corner of Perry township, and continuing in a south-south-western course to the southern part of Bethlehem township, crossing the Tuscarawas river about two miles above Bolivar; thence it bears more westward, crossing the south-eastern portion of Sugar Creek township, and the north-western corner of Wayne township in Tuscarawas county, entering Holmes county east of Weinsburg.

It is difficult to exaggerate the sharpness of this portion of the boundary line. Retracing our course, our notes show that the line bounding the till passes through the middle of Section 29, Canton township, where it crosses a small stream running to the north. This, like many other

similar cases, showed signs of having been dammed up, thus producing a small temporary glacial lake. To the north and west the till is continuous and probably of great depth; to the east it suddenly disappears, half way up a low hill. From Richville to the south-eastern corner of Perry township till and boulders are continuous, and the deposit apparently of great depth. One of the boulders a short distance beyond the till measured $6 \times 4\frac{1}{2}$ feet. A detour through Section 6, Pike township, and Section 32, Canton township, demonstrated a total absence of glacial signs in that region. The whole country to the south-east was broken and hilly, in striking contrast to that in the opposite direction, which seems to have been leveled up by glacial material. Upon the hills in Section 1, Bethlehem township, cuts in the till 6 feet in depth disclose large granitic boulders lying still deeper. The road running south, between Sections 11 and 12, and 13 and 14, is upon the very edge of the glaciated region. Detours of a few rods to the east lead into a region in which there is only rock in place and the soil formed by its disintegration. South-westward from this point to the river the boundary is near an unfrequented road passing one half mile north of the first Moravian settlement in this region.

At the upper end of the great ox-bow in the Tuscarawas river upon which Bolivar is built, but on the north side of the river, is an immense kame-like accumulation containing boulders from $2\frac{1}{2}$ to 3 feet in diameter. The terrace is here 36 feet above the river, and the kame-like accumulation is 118 feet higher. The space included in the ox-bow is occupied by a gravel deposit whose surface is 51 feet above the river. From this point down the river occupies a narrower valley, with diminishing terraces. Five miles below, at Zour, wells in this terrace 30 feet deep do not go through the gravel. Above the ox-bow, and on the west side of the river, opposite the kame-like deposit just described, the terrace is 61 feet, which continues up the river a mile or more without change.

Going west along a road near the county line in Bethlehem, a little till appeared when the higher land was

reached, but on ascending the hills to the left (south) it disappeared, and is wholly absent in the extreme south-western corner of Bethlehem township. But the hills in Section 30, immediately to the north, are covered with till containing large granitic boulders, some of which are between 3 and 4 feet in diameter. Till is continuous and of unknown depth all the rest of the way to Navarre, displaying to some extent the familiar kettle-holes and knolls of the moraine belt. The small streams emptying north also display the well-known signs of temporary ice-dams. One of the numerous boulders of red granite over this area was between 200 and 300 feet above the Tuscarawas river, and measured 7×5 feet, 3 feet out of ground.

The characteristics of the moraine just described continue through the southern portion of Sugar Creek township, crossing Sugar Creek below Beech City. One and a half miles below Beech City, towards Deardoff's Mills, the accumulations of gravel in the valley are immense. The valley is here about one mile wide. The gravel is thrown up into hummocks and ridges from 20 to 30 feet above the general level, enclosing many kettle-holes. The country from this point to Wilmot, and from Wilmot south to the county line, is completely enveloped in till. One boulder measured 7×6 feet, 2½ feet out of ground. But on the road from Deardoff's Mills, across the northern part of Wayne township in Tuscarawas county, toward Weinsburg in Holmes county, no till or boulders appear for several miles. The road leads over the summit of the land, and displays to good effect on either side the contrasts between the glaciated and unglaciated region. One mile and a half east of the Holmes county line granitic boulders begin to appear, and accompanied after a little with till, continue to increase to Weinsburg. This east and west road enters the moraine at an acute angle, the direction of the moraine being here west-south-west. The north-east portion of Paint township, in Holmes county, is covered with till to an unknown but evidently to a great depth.

3. HOLMES COUNTY.

The glacial boundary in Holmes county is very sharply defined, dividing the county into two nearly equal portions. It enters the county on the east, in Paint township, near the corner of Stark and Tuscarawas counties, and passes diagonally to the north-east corner of Berlin township, where it turns more nearly west, passing through Hardy township, crossing the Killbuck below Millersburg; thence, bearing slightly to the north, it passes through the center of Monroe and the northern part of Knox township, to the eastern side of Hanover township in Ashland county. Through all this distance the contrasts between the regions north and south of this line are very marked.

In Paint township there is but little till south of the diagonal road leading from Wilmot through Weinsburg to Berlin. Driving one quarter of a mile south of Weinsburg till suddenly disappears. There is a noteworthy collection of granitic boulders a few rods south-east of the village, at the crossing of the road from Slatersville. South of this there is no till. Occasional boulders were reported, but none were seen by us in a drive of half a mile. To the north and east of Weinsburg the deposit of till is continuous, and evidently of great depth. Weinsburg is on the watershed between Sugar Creek and Indian Trail Creek, and, according to our barometer, was 600 feet above the valley of the Killbuck at Millersburg. The south-western part of Paint and the south-eastern of Salt Creek townships are likewise covered with till, which is evidently very deep. A granitic boulder on the road between Weinsburg and Mount Hope measured 7×6 feet, 3 feet out of ground.

Berlin township.—A detour of several miles through the southern portion of this township disclosed no sign of glaciation, except in the valley of Dowdy Creek. In this valley there are extensive terraces down as far as within one mile of the southern boundary. At that point the terrace is 50 feet above the stream and about 150 yards wide, and contains some scratched pebbles. The boundary of the till runs between Sections 13 and 8, and crosses the western boundary of the township one half mile south of the road

running between Berlin and Millersburg. The elevation here is 475 feet (B) above the Killbuck. Granitic boulders are abundant all along this road. At Berlin post-office it is 600 feet (B). On driving north from Berlin post-office we strike immediately into till, which seems to be very deep. Near the corner of the road turning east one quarter of a mile north, in Section 6, are extensive kame-like accumulations containing numerous boulders, and enclosing a large kettle-hole. Till is continuous northward.

Hardy township.—On the road from Millersburg to Berlin till is found on the tops of the hills all along to the township line. Going east from Millersburg the first hill is 250 feet above the railroad, the second 350 feet, thence rising at the town line to 475 feet. The depth of the till is at least several feet. In Section 14 a boulder measured 7x5 feet, 3 feet out of ground. The most southerly deposit of till on the east side of the Killbuck is where the north branch of Sandy Run touches Section 16, two miles and a half south-east of Millersburg. Three quarters of a mile north-east of this point a small accumulation of till and boulders occur, at a height of 375 feet above the run; east and south the country is entirely free from it.

The terraces upon the Killbuck are extensive, both above and below the glacial limit. One mile and a half below Millersburg on the west side, on the farm of A. Uhl, is a terrace about a quarter of a mile wide, containing kame-like ridges and knolls, the surface of which is 102 feet above the flood-plain. This gradually rises until it is merged in the till of the hills beyond. Two miles further south, in the north-west corner of Mechanic township, near Stuart's Mills, the terrace is composed of finer material, and is level topped and gradually descends towards the south, being here but 71 feet above the flood-plain. Still further below the glacial limit at Oxford is a terrace on the east side of the creek, extending across the open ends of the ox-bow which the stream here forms. The intervale is here about one third of a mile wide, and 25 feet above low-water mark. The terrace is 76 feet higher. On the west side of the creek, between Shimplin's Run and Black Creek,

and one quarter mile west of the Killbuck, are terraces of fine material containing some granitic gravel, which are 61 feet above the flood-plain.

Driving up from Millersburg on the west side of the Killbuck, there are no terraces for the first mile. The valley is about one half mile wide. But just above where a small stream comes in from the west is a kame-like accumulation of coarse material, 50 feet in height, extending about one eighth of a mile. On the north side of this small stream the material is finer, and the surface much more uneven, extending to the road running over the hills to Holmesville.

Near Holmesville—five miles above Millersburg—Paint, Killbuck, and Martin's Creek come together nearly at right angles. About their junction there is an extensive intervale not far from two miles in diameter. The village is built upon a terrace about 25 feet above the intervale. Between the Killbuck and Martin's Creek, which comes in from the east, there is a kame-like accumulation of rather fine material (the pebbles being ordinarily not more than three inches in diameter) extending about one eighth of a mile N. W. by S. E. The surface is very much broken, displaying many kettle holes. A railroad cutting through it shows some scratched stones in the material, and a depth of 61 feet at the railroad ; but it rises about 40 feet higher to the north. From this point to Millersburg, on the east side, there are no terraces, the intervale being about one sixth of a mile wide. One half a mile north of Millersburg, as the road rises over the hill, a fresh cut in the till of 20 feet disclosed no bottom to it.

On the west side of the Killbuck, in Hardy township, till ceases two miles and a half south-west of Millersburg, on the farm of William Lisle. There is here a small stream, and the till appears upon the north side of the stream, but not upon the south. The general elevation of the country (which is much broken) is 350 feet above the Killbuck. South-east for two miles till is totally absent, while to the north it is abundant, and boulders are numerous. It continues west to the works of the Hardy Coal Company from which place to Oxford no till appears.

Monroe township.—From Oxford we drove in a north-west direction up a small stream which rises in the center of Monroe township. No boulders or till appeared below Centreville; but there were terraces of fine material containing some gigantic pebbles, and diminishing in height as we ascended the stream. North from Centreville granitic boulders began to appear, and were frequent all along up the valley to the watershed, where, near W. S. Carn's, a large deposit of till appeared, enveloping everything and forming large dome-shaped hills. Cuts from 10 to 15 feet disclose no rocks. The road is 300 feet (B) above the Killbuck, but hills covered with till are about 150 feet higher.

Oak Grove Nursery, a short distance to the west, is 475 (B) above the Killbuck. One quarter of a mile farther west, on lower ground, the deposit of till and boulders is very marked: one of granite measured $10\frac{1}{2} \times 6\frac{1}{2}$ feet, $3\frac{1}{2}$ feet out of the ground. Elevation 430 feet (B.) Till is continuous one mile west, and south to the farm of R. Martin. For the next mile and a half there were occasional boulders, but no till. On the next road west, struck suddenly into till by a school-house, whose elevation is 610 (B) above the Killbuck. Beyond this there were occasional boulders to the road near the western line of the township, leading to Napoleon. Some boulders were seen half a mile farther south. This is about five miles north-east of Napoleon, which is situated in the valley of Black Creek, which is about one eighth of a mile wide, and from 400 feet to 500 feet below the general level. A striking feature along this creek, and especially in the vicinity of Napoleon, is the great blocks of sandstone, formerly occupying the summits of the hills, which have been broken off, and have gradually crept down towards the bottom as the underlying shale and talus have been removed. These blocks are sometimes as large as a house, and are in all stages of advancement in their progress towards the valley. They resemble in most respects what is to be seen in the valley of the Allegheny south of Salamanca, and in the neighborhood of Rock City. Instead of being due, as some have supposed, to glacial action, these phenomena are pretty certain evidence of the

absence of any glacial movement, and exist either altogether south of the line of glaciation, or, as here and at Rock City, on the very margin, where the ice-movement ceased, and where glacial abrasion was reduced to zero.

Knox township.—From Napoleon we followed up the narrow valley of Black Creek on the road to Nashville. The valley continues to be about one eighth of a mile wide, and for five miles is remarkable both for the abundance of sandstone blocks referred to above, which are creeping down the sides, and for the absence of granitic boulders. Upon reaching the farm of A. Cline, a little south of the watershed, till appeared in great quantities. This is 375 feet (B) above Napoleon. From here to Nashville till is continuous for $2\frac{1}{2}$ miles, as also south-west of Nashville to the hill south of the farm of S. H. Vance. Boulders continued to the cross-roads south of the house of A. Bell, where all signs of glaciation had ceased. West of this there are no signs of glaciation as far as the next cross-roads. Elevation 450 feet (B) above Napoleon. Turning north, one mile brought us into a kame-like deposit in a shallow valley by the cross-road, near G. Uhlman's, one mile south of Washington township, and three miles east of Hanover township in Ashland county. This kame is about 25 feet high, and its course is nearly parallel with that of the shallow valley in which it is situated, which drains into the Mohican. What is marked near here, on the county atlas, as an ancient mound is more ancient than the map-maker supposed, it being not artificial, but a small mound of slate left by erosion. From here north-west to a point a little above the junction of Lake Fork with Mohican River, till and boulders are continuous. This is near the south-west corner (Section 12) of Washington township. From this point down to the junction and a half mile beyond is a terrace of very coarse material, largely composed of granitic pebbles. Elevation above the river 107 feet. No till was discovered in the western projection of Knox township. From this point we drove through Nashville to Millersburg, on a road parallel with the glacial boundary, and about two miles north of it. Till is continuous, and evidently deep,

there being but few out-cropping rocks in the whole distance. Cuts in the till frequently showed a depth of from 10 to 15 feet, with no signs of bottom. Two wells were reported on the hills crossed, as going 25 feet without striking rock. Boulders are everywhere abundant. To the north stretches the characteristic leveled area of the glaciated region. The ice, with its burdens, evidently came up to the watershed between Paint Creek and Black Creek—its serrated edge barely surmounting it.

4. KNOX COUNTY.

The boundary line of the glaciated region, which, in the western part of Holmes county, was bearing slightly northward, suddenly turns to the south in the eastern part of Hanover township, Ashland county; passing thence into Jefferson, the north-eastern township of Knox county, and thence through the western portions of Union, Butler, and Jackson townships, along the eastern margin of the county. The change of direction was so abrupt as at first to confuse, and afterwards to startle us. But, as usual, we found the departure from the general law of glacial movement less than would at first seem to be the case. From Salamanca, in New York, the moraine, with slight variations, bears continually southward, as well as westward.

Jefferson township.—There are a few granitic boulders, and some glacial gravel on the road from Jelloway to Greersville, one half mile east of Greersville. Near the same place on the Danville road, by the Methodist church, there is a larger collection of pebbles, and perhaps till. This is in a valley, on a branch of the Jelloway, running south. But the hill to the west is free from drift; likewise the hill to the east, occupying Sections 4 and 7, is without till. But in the valley of a small tributary to the Mohican, a little south and east, in Sections 3 and 8, there are accumulations of till in ridges from 10 to 15 feet high. These are best shown upon the farm of G. Greer, in Section 8. From this point to the south line of the township till is continuous, but does not extend eastward into Sections 12 and 19. The Cleveland, Akron, and Deleware Railroad enters the gla-

ciated region from the east through a cut in till, one mile east of Danville, and very nearly upon the line between Jefferson and Union townships. This cut is 375 paces long, and is from 20 to 36 feet in depth. The pebbles average from 2 to 3 inches ; but there are a few boulders of considerable size. The hills to the south east show no till.

Union township.—The village of Danville is built upon a hill in the extreme north-western part of the township. The height of this hill is by barometer exactly the same as that of the depot at Mount Vernon. This hill is composed of till. A. J. Workman reports a well 126 feet deep as passing through yellow clay, blue clay, gravel, quick-sand, and cemented gravel, and still not reaching rock. Another well of 65 feet, through similar material, was reported. One and a half mile south of Danville, on the Millwood road, a large deposit of till forms the divide between Owl creek and Mohican river. The east and west line of this deposit is sharply defined, running through the eastern part of Section 14 and the central part of Section 17, to Millwood. On the east side of the small brook, running into Millwood from the north, drift is absent ; but on the west side it is bounded by a range of gravelly knolls and kame-like ridges. These are composed of glacial material, and are 117 feet above the brook on the north of the village.

Butler township.—On the south side of Owl creek a thin deposit of till covers the whole western range in Butler township, the boundary line swinging a little to the east until it enters Jackson township in the north-eastern corner of Section 4. But the deposit is nowhere so marked in this township as to deserve to be called a "terminal moraine." The limit, however, is pretty sharply defined.

Jackson township.—In this township the boundary line enters upon the north, two miles east from Clay township, and continues in a south-easterly direction to the south line, about three miles east of Clay township. At the cross-roads in Section 8, we turned east into till of considerable evident depth. This disappeared in three fourths of a mile, and did not re-appear until we had gone one mile south to the church in Section 12, and turned west one half

mile. Here, on turning the summit of the hill, two miles north from the south, and $2\frac{1}{4}$ miles east of the west line, we struck into a continuous deposit of till stretching westward. This is upon the water-shed, and is 300 feet (B) above Wakatomaka creek. Upon crossing this creek, and striking the Zanesville road in the north-east corner of Eden township, Licking county, and driving north-west to Martinsburg, found till of great depth all the way. Occasionally the tops of the hills exposed rock in place, but Paul Run is nearly filled with till.

5. LICKING COUNTY.

The glacial boundary line enters Licking county in the north-east corner of Eden township, passes through the north-west corner of Mary Ann, the eastern sides of Newark and Licking townships, nearly on the line between the latter and Franklin and Bowling Green townships.

Eden township.—From Fallsburgh post-office to Simpkin's corner, in the extreme north-western portion of the township, the road follows the water-shed. No till or boulders whatever appear upon it. At Simpkin's corner a few granitic pebbles appear, but there is no till until reaching the farm of A. D. Larrison, in Eden township, one eighth of a mile south of the Knox county line, and three quarters of a mile west from the line between Fallsburgh and Eden township. This is upon a height of land about 350 feet above the creek, and granitic boulders three and four feet in diameter are abundant. Patches of till continued to appear upon the road following the water-shed south for $2\frac{1}{2}$ miles; crossed Rocky Fork near J. Elliott's; there was but little drift in this valley at this point. Upon ascending the water-shed to the west, in Section 13, found a considerable depth of till, which continued for a half mile west and a quarter of a mile south; but the diagonal road running south-east, and keeping along the water-shed between Rocky Fork and Wilkin's Run shows no till to the town line; but a few white granitic boulders were observed. Till, however, appeared $1\frac{1}{2}$ miles west in the valley of Wilkin's Run.

Mary Ann township.—The deposit of till is not continuous over the western part of Mary Ann but a considerable amount appears in Section 6, and the south-western corner of the township is completely enveloped in a deep deposit.

The terrace deposits in the neighborhood of Wilkin's Run post-office are noteworthy. One half mile south-west of the post-office this terrace is 92 feet high, and composed of water-worn pebbles with no large boulders. This continues up the small branch nearly to the line of Madison township, where it merges into the deposit of till. Two miles east of Wilkin's Run the deposit is still noteworthy, and presents the appearance of extensive kames. The south-west corner of this township, and the south-east of Newton, are deeply enveloped in till. Wilkin's Run was one of the glacial outlets, and the terrace deposits are such as usually mark the streams as they emerge from the boundary of the glaciated region.

Newark township.—At the city of Newark the three forks of the Licking River unite. All of these drain the glaciated region upon whose eastern border Newark is situated. The extensive gravel plain upon which the city is built is about 20 feet above the river, and is the deposit of these streams in the last stages of the glacial period when still swollen by the floods of the melting glacier; while terraces of a still higher altitude surround the plain, marking the size of the floods at a somewhat earlier date, when at their greatest extent. The terrace upon which the city cemetery is situated is 108 feet above Licking River. South-east of the city, a terrace near the river is something over 60 feet above it. The eastern limit of till in this township coincides in the northern part with the east line of the township, though in this part of the township many of the hills are free from till. As, however, you go east from the North Fork, along the town-line road, between Newark and Newton, the till appears to be of great depth, and stretches away to the north in such hummocks and ridges as usually characterize the moraine. The elevation here is 200 feet (B) above the North Fork. South of the city, on the Linnville road, till envelops everything to the summit of the high

lands, where it is evidently of great depth. The elevation is about 300 (B) above Newark.

Licking and Franklin townships.—The glacial boundary follows very closely the line between Licking and Franklin townships. To the west everything is enveloped in till; to the east are the familiar rocks and gorges of the unglaciated region. Many boulders were found, and a considerable amount of drift, along Claylick Creek, in the center of Franklin township. This, however, seems to be a water deposit, formed by streams and floating ice, which came over the low place between Swamp Run and Claylick Creek. The gap in the watershed between these streams is 150 feet lower than that of the hills to the north and south, and the valley through which Claylick Creek now empties to the north appears to be very narrow. There certainly is no till on the hills, either to the north-west or south-east of this depression. The road along the town line, from Hog Run to Amsterdam, in the south-west corner of Franklin, is all the way over a deep deposit of till containing many granitic boulders. Amsterdam is 400 feet (B) above Newark, and commands a most extensive view of the fertile and level glaciated region to the west, and of the broken region to the east. Near the Presbyterian Church, upon the most commanding point near Amsterdam, is an Indian mound 21 feet high, and 124 paces in circumference. East of Amsterdam a drive of three miles to Linnville disclosed no till, but south and west the deposit is continuous and deep. In the south-eastern part of Licking township, east of the reservoir, the road runs for half a mile upon the summit of a ridge of kame-like hills containing many granitic boulders. This ridge seems to cross the valley, and to be a true moraine barrier, restraining the waters of Reservoir Lake. The railroad near here shows very good sections of this ridge, and of other ridges parallel to it. They are from 15 to 30 feet above the level of the valley, but how much of their base is obscured by subsequent deposits there is no means of telling. Through this depression east of the reservoir, on the line between Licking and Perry counties, there was evidently a great overflow of glacial water, emp-

tying through Jonathan Creek into the Muskingum, below Zanesville.

6. PERRY COUNTY.

The moraine passes in this county, in a north and south direction, through Thorn and Reading townships.

Thorn township.—We have already described the glacial accumulations east of the reservoir, where they pass from Licking county into this township. The reservoir occupies a great kettle-hole. The railroad which here cuts through the moraine follows for several miles towards the south-east an outlet for the glacial floods. This occupies a valley about a mile wide, through the middle of which kame-like ridges of gravel 15 to 20 feet in height extend; but these are flanked on either side by deposits of black muck. On turning up a tributary towards Somerset these deposits cease. The headwaters of the stream are in an unglaciated region.

Thornville is upon a hill of till containing numerous granitic boulders, and which is about 300 feet (B) above Newark. A well upon this hill was reported as passing through 10 feet of soil, 25 feet of blue clay. South-east from Thornville the till is, for the first mile, very deep, with very numerous and large granitic boulders. Till continues a mile farther to Section 23, and thence south to the north-west corner of Reading township. But from Section 23, Thorn township to Somerset, (seven miles south-east,) and thence west to the branch of Rush creek, a mile west of New Reading, the county is wholly unglaciated.

Reading township.—The north-western section of Reading township presents a level and rich expanse of territory, produced by the glacial floods coming down from the southern part of Thorn township. The contrast between the western sections of this township and everything east of Rush creek is very marked. The road running south, near the western line of this township, is through a region deeply enveloped in till, as far as the pike, a little east of Rushville. A drive on the pike of half a mile into Reading township toward Somerset, brings one into the unglaciated region.

7. FAIRFIELD COUNTY.

The glacial boundary enters Fairfield county a little south of the Somerset and Lancaster pike in Richland township, and crosses the north-west corner of Rush Creek township, the south-east corner of Pleasant township, the north-west corner of Bern, through the center of Hocking township, and the western sections of Madison township to the line between Pickaway and Hocking counties.

Richland township.—The Somerset and Lancaster pike suddenly enters extensive deposits of till upon passing from Perry to Fairfield county, a mile and a half east of East Rushville; but a drive of a half mile south carries one entirely beyond the range of till. From Rushville one must drive a mile and a half south to reach the unglaciated district. But here on both sides of the creek the passage from the glaciated to the unglaciated is sudden. On the north part of H. Geiger's farm, east of Rush Creek and one half mile north of the township line, the glacial limit is marked by hummocks of till which are at least 50 feet in depth; while on the west side of the creek the boundary is near the town line in Rush creek township, on the farm of J. D. Martin. Large granitic boulders abound along the glaciated margin through Richland township. The elevation is 250 feet (B) above Lancaster and about 200 feet above Rush Creek. There is no barrier in this vicinity to stop the southern progress of the ice. A detour of several miles to Bremen demonstrated the absence of till to the south-east.

Rush Creek township.—The characteristics of the glacial boundary through Rush Creek township are very similar to those in Richland. The remnants of a boulder of dark, hornblendic rock, on the farm of J. D. Martin, one fourth south of West Rushville, measured $10 \times 8 \times 3$ feet out of the ground. Probably one third had been removed by blasting. The elevation is 250 feet above Lancaster, and there is no southern barrier to account for the sudden termination of the till. Four or five miles to the south, across the valley of the west branch of Rock Creek, an escarpment of Waverly sandstone hills is a striking feature of the landscape. There is no till in Sections 17 and 18 of this township.

Pleasant township.—From Rushville to Lancaster the pike bears southwest. The glacial boundary enters Pleasant township, one mile south of the pike, intersecting the pike again near where it passes from Pleasant township to Bern. The road running to Lancaster, parallel with the pike, and about one mile north-west, is through a region everywhere enveloped with till, a great amount of it resting upon the hills 250 feet above the city. It is at the intersection of this road with that to Pleasantville that the celebrated granitic boulder referred to by Professor Andrews (see his *Geology*, pp. 211, 212) is found. This is in the valley of Baldwin's Run, is hornblendic in character, and measures $18 \times 12 \times 6$ feet out of the ground. Boulders were left upon the summit of Pleasant Mountain, a mile north of Lancaster, and about 300 feet above it.

Bern township.—The moraine enters the north-west corner of Bern township, near the city of Lancaster, but its course is here somewhat disguised by the water action in the Hocking Valley, which it here intersects. The Cincinnati and Muskingum Valley Railroad, east of Lancaster, passes through a low valley into the tributaries of Rush Creek. This valley is bounded upon the south by an escarpment of Waverly sandstone, rising about 250 feet. A drive across the country, back of this escarpment, from Lancaster to Bern Station, failed to disclose any signs of glaciation; but the valley itself is partially filled with gravel, brought in by the various glacial tributaries from the north. This deposit of gravel is especially noticeable near Bern Station, where the gravel accumulation brought down by Racoon Creek forms a hill 50 or 60 feet in height. Till and boulders appear between the Logan and Chillicothe road, at an elevation of about 50 feet, one mile south of Lancaster.

Hocking township.—The course of the Mayesville and Zanesville turnpike, through Hocking township, is everywhere over a vast deposit of till. This is true not only when it follows up the valley of Hunter's Run, parallel with and close to the railroad, but after it crosses the railroad to the south, and rises upon hills which are 450 feet

above Lancaster, near the south-west corner of the town. Here the till is piled up to a great height, upon the summit of the sandstone escarpment which overlooks the plains to the north, made smooth and fertile by glacial action. On the farm of S. Peters, in Section 20, 450 feet above the canal at Lancaster, a well was reported 40 feet in till; another, near by, 20 feet. The parallel road, two miles south-east, shows no till from Hamburg post-office toward Lancaster, for three miles, to its intersection with Arney's Run; for the rest of the distance till is continuous and deep. But occasional granitic boulders crown the summit of the sandstone hills running parallel with these roads and halfway between them, and rising 450 feet above the canal. Muddy Prairie, in the south-western corner of this township, is a shallow kettle-hole of great size, which has been filled by the accumulation of peat. Its natural drainage is by a long circuit to the west, but by a little ditching it is made to empty by a shorter course through Muddy Prairie Run.

Madison township.—On leaving Lancaster the glacial boundary turns rapidly toward the south, and passes through Madison township nearly in a north and south direction, through Sections 4, 9, 16, and 21. It crosses Clear Creek at Clearport, near the junction with Muddy Run, at an elevation of about 200 feet (B) above Lancaster. Everywhere along this distance the glacial accumulation abuts closely against an escarpment of Waverly sandstone; yet covers hills to the west, in Clear Creek township, of equal height with them, namely, 450 feet above Lancaster. The line bends a little west as it emerges from this township, and enters Hocking county.

8. PICKAWAY; AND 9. HOCKING COUNTIES.

The moraine follows so nearly the line between Pickaway and Hocking counties that we shall do best to consider them together.

Driving east from Tarleton, in Pickaway, to the line of Hocking, till and granitic boulders are continuous and abundant to the Hocking line, and for nearly a mile farther

east; but here they suddenly cease, and do not re-appear on turning north until reaching Section 20, in Madison township, Fairfield county. Driving south-east from Tarleton, till is continuous until crossing the county line, north-west of South Perry post-office. A section of till upon the county line here shows at least 30 feet in depth. The elevation is 300 feet above Circleville. One mile east of the county line till had entirely disappeared. There is no till in the valley of Laurel Run for a mile and a half west of South Perry. Hills of Waverly sandstone arise on every side about the village. There is no till upon them, but a granitic fragment 6 in. by 4 in. was found upon a hill a few rods north of the village, and 225 feet (B) above it. This is 300 feet above Circleville. Across the Run, on the south side, the ridge road to Adelphi rises 375 feet in one and one half miles, and turns west upon the summit, near the southern line of Perry township, and three miles from its western boundary. This is by barometer 450 feet above Circleville, and the level touches the tops of the hills in all directions. This road continues for three miles west upon the summit of a narrow ridge of sandstone, left by the erosion of the streams. From it one looks down on either side into gorges between 300 and 400 feet in depth. On driving upon this ridge about three miles westward, we struck a collection of granitic pebbles upon the very summit, about one mile north-east of the south-west corner of the township. The pebbles were small, but of a variety of kinds. Three fourths of a mile farther west, while still 275 feet above South Perry, began to find till. Granitic boulders continue frequent to Laurelville, at the junction of Salt Creek and Laurel Creek. The level of the stream is here 75 feet lower than at South Perry.

10. ROSS COUNTY.

Nowhere in Ohio is the glacial boundary marked by larger accumulations than in Ross County, through which it extends diagonally from the north-east corner to the south-west—passing through the north-west corner of Colerain, the southern part of Green, the southern part of

Union, the northern edge of Twin, the south-eastern part of Paint, and the western part of Paxton townships.

Colerain township.—The village of Adelphi occupies the north-east section of Colerain township, and is built upon an irregular deposit of till worthy to be compared with the terminal moraine on Cape Cod in Massachusetts, and with that upon the Pocono plateau in Pennsylvania, and that west of Canton in Stark county. Salt Creek bursts through this moraine a few rods north-east of the corner of the county, and makes off to the south-east, through a narrow valley 450 feet deep, and for a short distance is bounded on the east by extensive gravel terraces. The moraine accumulation upon which Adelphi is built abuts upon this creek towards the east, and there is here a perpendicular exposure of till 188 feet in depth. The creek is constantly undermining it, and an extensive slide is in progress which has already carried away a considerable portion of the cemetery. The height of this cemetery was taken by level. West of the village where the land is higher the barometer indicated more than 200 feet. On driving south from Adelphi, up Brimstone Hollow, till continued for one mile, and occasional granitic pebbles were found for two miles farther, where the summit of the Waverly sandstone escarpment was reached, at a height of 400 feet (B) above Salt lake. Turning west upon this ridge, a little till was found upon the very summit after going a mile, and just before beginning to descend towards the north into the valley of Reed's Ford. On descending into this valley, a hundred feet or more, drift began to appear. This was at first water-worn, and in terraces, as would be natural in a valley beginning, as this does, a little south of the glaciated line, and opening to the north. On reaching Section 14, near the residence of Isaac Delong, till appeared in large quantities, with many granitic boulders, some of them from 6 to 8 feet in diameter. On going a mile and a half farther north, this road reaches the turnpike, two miles from Adelphi, which, over all this distance, follows the summit of a true moraine deposit. To the north-west stretch the fertile plains of Pickaway county, lying fully

150 feet lower than the summit of this moraine. To the south rises, near by, the escarpment of Waverly sandstone, which forms the north-western boundary of the great coal formations of the State. The granitic pebbles which we had found upon the summit of that escarpment in Ross, in Hocking, and in Fairfield counties, show that the ice was at least 400 feet thick over all the plains to the north.

This moraine ridge continues south-west from Adelphi in about the same proportions, and in similar relations, to the plain upon the north, and to the hills upon the south, until it enters Green township, two miles from the southern border. All along through Colerain township, in driving a mile south from the pike, one strikes out of the till, and after crossing a little valley, plunges into the deep gorges which everywhere characterize the sandstone regions beyond. Professor Orton had noted the boundary with great accuracy. (See Ohio's Geol. Report, Vol. II, pp. 651, 652.)

Green township.—The moraine enters Green township from the east in Section 24. Till continued to the northern edge of Section 25, where it suddenly disappeared on the water-shed. A drive of two miles south into Harrison township demonstrates the total absence of till over the south-east corner of Green. On driving over the diagonal road north-west till appeared at the water-shed in Section 25, nearly one mile from the south line, and a mile and a half from the east line of Green township. The accumulation of till is large along the road between Sections 26 and 27. The diagonal road running south-west through Section 27 seems directly upon the moraine, and between this glacial accumulation and the rocky hills to the south there is a space of about half a mile, occupied by a small stream whose head-waters are in Section 33. In the southern part of Section 29 there are enormous kame-like ridges of gravel, from 100 to 150 feet (B) in height, and running north and south. The material of this kame is rather fine, and is largely composed of limestone pebbles. The Pickaway plains here contract into the valley of the Scioto, which, through the rest of its course, is nowhere more than two or three miles wide, and is bounded on either side by pre-

capituous hills of slate and sandstone. In the north-east corner of Section 31, the water-worn material of the kame gives place to till, which contains many granitic pebbles a foot or more in diameter. In crossing the head of the Scioto Valley, on a road running east and west through this point, three parallel ridges are encountered, running nearly north and south, each one in order toward the river extending farther south.

Springfield township.—About half way between Hoptown, in Springfield township, and Chillicothe the first terrace (over which the railroad runs) is about a half mile in width. The second terrace, which occupies the remaining space to the hills on the east, which is also about a half mile in width, rises abruptly 48 feet above the river.

Union township.—In driving up the Scioto upon the west side, from Chillicothe, the road follows the first terrace, which is about a mile wide, and 20 feet above the river. Kame-like ridges appear in Union township, nearly opposite the south-west corner of Green, and just above the second toll-gate, where the Clarkson pike branches off to the west. The cross-road leading directly west from this point ascends 400 feet (B) in the first mile. Granitic boulders are abundant at this elevation, and a well one half mile south passes 33 feet through what was called "gravel," but is doubtless "till." Granitic boulders appear upon this plateau for a half mile or so farther south. The till is of great depth, one half mile north of the centre, on the farm of J. A. Hurst. From the centre, south-west, past the houses of M. A. Pinto and W. R. Bowdle, to the Frankfort pike, the road continues upon the highlands, and passes many granitic boulders, and through occasional deposits of till, but the till is not deep. There is considerable development of till at the cross-road near the house of Susan Beard, and again, upon descending the hill to the turnpike near the house of Jacob Flescher; but no till appears along the pike to the west for a mile, where, upon descending about 150 feet, the road enters, at about 150 feet above the north fork of Paint Creek and about a mile and a half east of Frankfort in Concord township, a deposit of

till which is unbroken to the north and north-west. The railroad from Chillicothe to Roxabel strikes into extensive drift deposits at Anderson's, upon the north fork of Paint, which is specially abundant at Musselman's. The deposit here is at least 25 or 30 feet deep, and looks like till, though the material is very fine.

Concord and Twin townships.—One half mile south of Musselman's, upon the Greenfield pike, in Twin township, there is a small deposit of till, near the school-house, upon the farm of C. C. Plyley. The road is here 550 feet (B) above Chillicothe, and continues at this height west to Lattaville, in Concord township. A mile east of Lattaville, a well upon the farm of J. McConnell passed through 12 feet yellow clay, 3 or 4 feet blue clay, 10 feet yellow clay, 5 feet gravel. About thirteen feet from the top a piece of wood 3 or 4 feet long and 3 inches through was found in clay. From this point the eye surveys a vast extent of till in the valley of the North Fork of Paint, which is about 400 feet lower. But the hills facing the north are here completely enveloped in till. The ice seems for a long while to have crowded down to this rocky escarpment, and for a short time to have overlapped it upon both sides of the North Fork.

Lattaville, in Concord township, is built upon a striking development of the moraine. The turnpike follows the moraine across the south-east corner of Concord township. The general elevation is from 150 to 200 feet above the valley of the creek, while knolls and ridges of till rise 50 or 60 feet higher. About one mile south is the continuation of the rocky hills 200 or 300 feet higher, through which the North Fork of the Paint Creek has cut its way below Frankfort. One mile south of Lattaville till and many granitic boulders appeared near T. M. McDonald's upon the very summit of the plateau, 625 feet (B) above Chillicothe. A mile south-west, upon the other side of the water-shed, in the upper valley of Lower Twin Creek, there is a small amount of till near the school-house. South and east of this to the valley of Paint Creek there is no more till. There are some remarkable kames and terraces in these two

townships which deserve notice. As we have said, the North Fork of Paint Creek, above Frankfort, flows through a broad expanse of glaciated country everywhere enveloped in till and dotted with granitic boulders. Two miles south-east, near Musselman's, it enters a narrow valley about 400 feet deep, and a half mile wide, in which it continues for about 5 miles; when it comes out into a broader valley, and flows south-east until it unites with the Scioto below Chillicothe. Before the river enters this gorge separating Union from Twin townships, the valley is marked by numerous kame-like ridges, running nearly parallel with the stream. Between Frankfort and Roxabel numerous kettle-holes appear. One and a half miles south of Frankfort, on the south side of a small tributary to the creek, is a kame 57 feet above the general level of the valley. Granitic pebbles are numerous in this. One near the summit measured 3 feet. This kame runs at least three fourths of a mile to the south-east. Upon emerging from the gorge below Frankfort, in the eastern angle of Twin township, between Paint Creek and North Fork, extensive kames are found to connect the two valleys along the line of Cat Tail Run. The material in these kames is water-worn, and ranges from pebbles of granite 2 feet through to fine sand. Granitic boulders 3 feet through occur on the top of the gravel ridges. These ridges are more than 180 feet high, and descend upon each side at an angle of 25 or 30 degrees. Near the residence of Captain Phil. A. Rodes, facing Paint Creek, near the outlet of Wilcox Run, the kame is 158 feet high, and encircles a kettle-hole of great dimensions.

It is very clear, as Professor Orton surmised (see Geological Survey of Ohio, vol. II, p. 653) that Paint creek, in pre-glacial times, passed northward, and joined the North Fork, near the eastern angle of Twin township; but in glacial times that outlet was obstructed by ice, and partly filled with gravel, so that the creek left its broad valley and has cut a channel for three miles across the rocky escarpment which here formerly separated it from the Scioto. This post-glacial channel which it now occupies is "not more than 200 feet in width at the base, is bottomed with

rock, and is bounded by precipitous cliffs not less than 300 feet in height. After following a south-east course for three miles, it turns again to the north-east, and regains its old valley two miles west of the south line of Chillicothe."

From the fact that the old valley of Paint creek is filled only to about one third the height of the surrounding hills, it seems clear that the ice-front itself rested over the eastern angle Twin township long enough for the creek to wear the gorge just described to nearly its present depth. Perhaps this would require 2000 or 3000 years.

Buckskin township.—The boundary of the deep accumulation of till enters Buckskin township a half mile or more south of the Greenville pike, and crosses in a pretty direct line to Paint township, one half mile or more south of Salem. The road from the Greenville pike, near Henry Parrett's, to Salem, leads over a continuous deposit of till thrown up into low hills and ridges. The rocky escarpment extending from the Scioto river through Union and Twin township, crosses Buckskin township about a mile and a half south-east of Salem. We did not ascend it in this township, but from what we have described in Twin township, and from what we shall describe in Paint township, it is probable that the ice-sheet overlapped these hills, which are all along from 400 to 500 feet above the land to the north.

Paint township.—With the exception of the north-western corner, Paint township consists of sandstone ridges left from the erosion of a continuous plateau, which was from 500 to 550 feet (B) above the valley of Paint creek at Bainbridge. The ice surmounted these summits, and left considerable deposits of till and granitic boulders upon them, near the residence of D. H. Pricer, 3 miles south of Salem, and at various places along the ridge road south to Bainbridge as far as Henry Benner's. Near D. H. Pricer's, at an elevation of 550 feet (B) above Bainbridge, was a boulder of hornblendic rock about $5 \times 3 \times 2$ feet. Many boulders $2\frac{1}{2}$ feet through appeared at this elevation farther south.

Paxton township.—No till was observed in Paxton town-

ship, except near the woolen factory on Buckskin creek, whence it appears at intervals both on the road leading up the creek to the north, and also on the road to the right, leading upon the hill along which we marked the line of till and boulders in Paint township. A little till also appears in the north-western corner of the town, near Rocky Fork.

Bainbridge is in a valley about a mile wide, which has been cut down through parallel strata of sand rock and shale to a depth of about 500 feet. The village is built upon a terrace whose surface is about 25 feet above high-water mark. The material varies from coarse sand to well rounded pebbles 4 or 5 inches through. Limestone prevails, though granite is also present. A granitic boulder 4 feet in diameter was observed. One mile west of Bainbridge the terrace rises suddenly 15 feet. Just below the junction of Rock Fork till appears in small hillocks. The elevation is 125 feet (B) above Bainbridge. From this point to Hillsboro, in Highland county, signs of glaciation are continuous.

11. PIKE COUNTY.

Following south from Paint Creek, along the Ross county line, till disappears suddenly one quarter of a mile north of Cynthiana, in the extreme north-west corner of Pike county. To the west and south-west till is abundant.

12. HIGHLAND COUNTY.

The boundary enters Highland county, near the north-east corner of Brush Creek township, and continues, in a south-west direction, to Marshall township, about one mile north of its south-east corner. The deposits are continuous along the road from Cynthiana to Carmel post-office, south south-west to the school-house by J. West's, near the head of the middle fork of Brush Creek, and three-quarters of a mile south of the road from Sinking Spring to Marshall. To the south-east of this line across Brush Creek township, there are hills of sand rock and shale of great height. On the east side of these hills, two miles south of Carmel post-office, near the residence of D. W. Schamma-

horn, there is, however, an extensive deposit of till, which continues on the road south nearly to Baker's Fork, but there disappears. From this point around to Cynthiana no till was observed.

Marshall township.—There are heavy deposits of till all over the northern part of Marshall township. It is specially abundant south and west of the village, with many granitic boulders 3 and 4 feet in diameter. Towards the south-east part of the town the spaces upon which there is no till are extensive. But at the corner, by Jacob Kesler's, is a small deposit of till, with granitic boulders. There is none upon the road east to Bush creek, and none south to Jackson township. The distance from each of these townships is about a mile. But a half mile west from Mr. Kesler's an extensive and deep deposit of till begins, and is continuous to the west for at least a mile.

Jackson township.—The moraine may be said to enter Jackson township one mile north-west of North Uniontown. Upon the road from Marshall to Belfast till is continuous to the West Branch of Elk run, and on the road from Uniontown to Belfast there is no till for two miles. Upon descending to Elk run, near R. B. Matthews', granitic pebbles appear at an elevation of 50 feet above the bridge. Upon ascending the west bank there were occasional appearances of till all along, which, at the cemetery, near J. Weaver's, one half mile north-east of Belfast, was very abundant. From Belfast, upon the pike towards Hillsboro, saw no till for three miles; but there was an occasional boulder, one of which, a mile north of the township line, was between three and four feet in diameter. North of this till was continuous. West of Belfast no till appeared in the valley of Brush creek; but two miles north-west, near Joseph McCoy's, was a considerable deposit of till. Granitic pebbles occurred upon the ridge a mile farther south, near the school-house, by Mrs. Phoela Ford's. This is at an elevation of 600 feet (B) above Cincinnati, and 400 feet (B) above Belfast. On the ridge road from here to Newmarket there was scarcely any till, but scattered granitic pebbles. The elevation is between 600 and 700 feet (B)

above Cincinnati. From Newmarket there was a continuous sheet of till, in places very deep.

Along the town line south of Fairfax to Adams county there is a continuous and extensive accumulation of till at an elevation of 650 feet above Cincinnati. Upon the road running south-east from Fairfax granitic boulders are occasionally found for three quarters of a mile, but beyond that are absent, and no more could be found upon the east side of Rocky run.

13. ADAMS COUNTY.

The boundary line of the glaciated region enters Adams county in the north-west corner of Scott township, near the line between Concord and Jackson township, in Highland county. Between Winchester post-office and Mount Lee the till is nearly continuous, though not deep. The west fork of Brush creek is remarkably free from drift material, and no till appears on the road from Mount Lee to North Liberty. On the railroad from Winchester to Youngsville, on the east side of Elk run, two miles from Winchester, is a cut in till from 10 to 20 feet in depth. Angular granitic boulders are found near here from $2\frac{1}{2}$ to 3 feet through. On the road north-west from North Liberty large deposits of till occur, near Elk run, two miles south-east of Winchester village. The deposit was from 5 to 20 feet in depth. In driving from Winchester to Eckmansville, on the south border of Wayne township, till is continuous until within a mile of Eckmansville, where it disappears. On turning south-west from Eckmansville, across the north-west corner of Liberty township, the deposit of till is reëntered near the county line.

14. BROWN COUNTY.

On the road from Eckmansville to Ripley till is continuous through Byrd township. Two miles and a half south-west of Decatur, near the Christian Church, and not far from Jefferson post-office, is a granitic boulder two or three feet through. Till continued to Red Oak post-office, in Jefferson township. The road from here to Ripley descended through a gorge 450 feet deep. Found some small

pebbles upon the summit of the hills north of Ripley ; also in Lewis township, upon the summit of the hills, 2 miles north of Higginsport, found thin deposits of till. A granitic boulder measuring $2\frac{1}{2} \times 3\frac{1}{2}$, and $1\frac{1}{2}$ feet out of ground, was found in a small brook about half way up these hills. Franklin and Washington townships, in Clermont county, I have not examined, but I presume the glacial boundary approaches pretty close to the river. (See remarks below upon Kentucky.) Mr. Charles W. Smith informs me that there are small granitic boulders on the high lands two or three miles north-east of Ripley, and that on the highest hills in Ohio, opposite Augusta, Ky., pebbles of diorite and jasper are abundant, but diligent search upon the Kentucky hills near Augusta disclosed nothing but local *débris* of the stratified rocks of the region, except an occasional quartz pebble as large as the end of one's finger.

15. HAMILTON COUNTY.

At Walnut Hill Station is an extensive deposit of till from 10 to 20 feet in depth. Scratched stones and small granitic fragments are abundant in it. This is about 350 feet above the river. At North Bend the Cincinnati, Indianapolis, and St. Louis Railroad passes from the valley of the Ohio to the valley of the Miami by a tunnel, through an extensive deposit of till. The height of this deposit above low water-mark is upwards of 160 feet. No large granitic pebbles were seen in it, but the examples of striated pebbles were numerous and excellent. Below North Bend the space between the Ohio and the Miami is occupied by a remnant of the limestone plateau through which the rivers have worn their present deep channels. This is 375 or 400 feet (B) above the river, and is about 4 miles long and 2 miles wide. Till and granitic pebbles 2 feet through are found upon this summit. They are also found in Indiana upon the summit, of equal height to the west and southwest, across the broad valleys of the Miami and the White Water.

In Kentucky.

The glacial boundary enters Kentucky in CAMPBELL COUNTY, crossing the Ohio River about two miles north of the Pendleton county line. I have not examined sufficiently the northern part of Campbell county, and I can only fix the limit near the river. We crossed the river from New Richmond, Ohio, and ascended through the channel of a small brook to the summit of the Kentucky hills, near Carthage. These hills are about four hundred feet above the river, and the ascent is very steep. Granitic pebbles were numerous in the bed of this small stream, and, upon reaching the summit, we found the surface covered with till to the depth of ten or fifteen feet, in which granitic boulders a foot through were numerous, and in which it was not difficult to find beautiful specimens of scratched stones. From this point we went south, keeping upon the summit of the plateau from one and a half to three miles from the river. Indications of glacial action continued, but in a somewhat diminishing degree, until reaching Flag's Spring, where they ceased entirely. But to make sure, we went on in the same direction about four miles farther, and came down to the river at Motier, without seeing any farther glacial marks. At Flag's Spring there is an extensive accumulation of post-glacial conglomerate like that at Split Rock, soon to be described.

KENTON COUNTY.

My examination of Kenton county has been too brief to be very satisfactory, but what I have seen may serve as a guide to others. Three miles south-west of Covington the hills are covered with loam from 15 to 40 feet deep, at an elevation of 400 feet (B) above the river. There are occasional small quartz pebbles in this loam; but I saw no sure signs of the actual presence of ice. In my notes I have said: "This seems like the bottom of a temporary lake when the ice dammed the river below." On going across from the pike a little south of this, so as to strike the Licking River, two miles south of Covington flats, no glacial marks were observed. At Erlanger, however, the first

station south of Ludlow, on the Cincinnati Southern Railroad, a railroad cut shows clay to a depth of six feet or more containing pebbles of quartzite, limestone, and occasionally granite, near the bottom. All, however, were small, none of them more than three inches in diameter. The elevation is about five hundred feet above the river.

BOONE COUNTY.

The glacial deposits over the northern part of Boone county are unmistakable in character. On ascending the hill along the line of the Covington and Petersburg pike from Ludlow to Hebron, we encountered about one mile east of Hebron, and about 450 feet (B) above the river, a deposit of till, twelve or more feet of which in depth is exposed by a little stream running to the north. The whole surface of the country about Hebron is covered with a loamy deposit containing occasional scratched stones and granitic boulders. On ascending the hill from Taylorsville to Hebron small granitic boulders abound all along the bed of the little stream, and are found of considerable size in the clay upon the summit. On the pike between Florence and Burlington, and two miles east of Burlington, where a small tributary of Gunpowder Creek, which runs to the south, crosses the pike, a large number of granitic boulders are collected, they having been washed out of the till which caps the hills. The elevation above the river is 400 feet (B). Three fourths of a mile to the east the elevation is 575 feet (B,) and the headwaters of this tributary, a mile and a half or two miles north, near Hebron, are 500 feet (B). I counted within a few rods of each other 15 granitic boulders, one of which measured $2\frac{1}{2}$ feet in diameter. There were three or four boulders composed of metaphoric conglomerate, containing the beautiful red jasper pebbles characteristic of the eastern shore of Lake Superior, and of the region north of Lake Huron. They are identical in composition with boulders that are scattered over Michigan, Northern Indiana, and with one in the Oberlin Museum, found by Professor Allen in Brownhelm. Colonel Whittlesey brought a mass of this rock from its native ledge, near

Lake Superior, on the west side of St. Mary's River, and has adorned the yard in front of his residence with it. These boulders in Kentucky are found about five miles south of the Ohio River, and south of the water-shed in that part of the county.

In a drive from Petersburg to Hebron, the hills were found to be covered with till to a height of several hundred feet. The barometer read about 400 feet above the river. The redness of the soil was everywhere noticeable, showing that the iron was thoroughly oxidized. A detour to the south, from Florence to Union, and from Union across Gunpowder Creek, towards Bellevue (now called Grant P. O.), demonstrated the absence of glacial deposits until reaching the head-waters of Middle Creek, about half way between Burlington and Bellevue. Here the tops of the hills are covered with a gravelly deposit, containing occasional granitic pebbles several inches in diameter. Near the head-waters of the southern branches of Middle Creek, and especially at Rock Spring, the deposits are of very coarse material, are of great extent, and are cemented together by an infiltration of lime like that already spoken of at Flag's Spring, and soon to be described at Split Rock. This conglomerate consists largely of pebbles of limestone, but contains also granitic pebbles. It was noticed as early as 1845 by Professor Locke, and described in the *Cincinnati Gazette*, and more recently by Dr. Sutton, of Aurora, who specially notices its great elevation above the river. Dr. Sutton's paper may be found in the proceedings of the A. A. A. S. for 1876, and reprinted, with additional information, by Prof. E. T. Cox, in the *Geological Survey of Indiana* for 1878, pp. 108-113.

The most accessible place in which to study this deposit is near the mouth of Woolper Creek, about four miles north-west of the head-waters of Middle Creek, and about four miles south of Petersburg. The formation is here known as "Split Rock," and rises directly from the Ohio River, both above and below the mouth of Woolper Creek. Professor Locke "regarded this conglomerate as evidence of the destruction of a great arch of rocks which united

the coal-fields of Ohio with those of Indiana and Kentucky." Mr. Robert B. Warder, in the Geological Report of Indiana for 1872, also directs attention to this Split Rock conglomerate, and suggests, possibly, it is the terminal moraine of an ancient glacier. With this view Dr. Sutton and Professor Cox substantially agree. But Dr. Sutton and Prof. Cox suppose that the deposits upon the highland above Middle Creek are far more ancient than those in the valley of the Ohio about the mouth of Woolper Creek. As we read the facts, however, now, in the light of the most recent investigations, these deposits upon the highlands of Boone county and at Split Rock are probably contemporaneous, the ice of the glacial period extending down to a continuous line which crosses the river at Woolper Creek. The vast current of water which flowed down at the melting of the continental glacier was not determined in its course by the present channels as now, for these were in many cases filled with ice, and for a time the southward flowing currents were borne completely across the channel of the Ohio, flowing in a trough of ice, whose bottom was as high as the summit of Boone county.

The pebbles in the cemented mass of Split Rock are mostly of limestone, and are very coarse--individual pebbles frequently being from three to four feet in diameter. Granitic pebbles are infrequent. One was found, however, measuring two feet in diameter. The cliffs of this conglomerate, at the mouth of Woolper Creek, rise not far from one hundred feet above the river, and the material is cemented together by an infiltration of lime. Kame-like ridges extend for two miles south of Woolper Creek, on the way to Bellevue. These are composed of rather fine material, and are 160 feet above the river. The terrace upon this, the Kentucky side of the river, is, for two miles or more below Woolper Creek, remarkable for its height, being more than 100 feet above the river, and 56 feet higher than the high-water mark of January, 1883.



CHAPTER XIX.

In New Jersey.

[Professor George H. Cook, State Geologist of New Jersey, published in his annual report of 1880 the results of protracted study of the Drift-covered portion of that State and of the course of the Terminal Moraine. In his introduction he says:—

“The great ice sheet was several thousand feet thick in New England and New York. Near its southern limit, in our State, it diminished to less than 1,000 feet, and did not cover the higher crests In the unsorted or true Drift there are no extended lines of stratification. The materials appear to have fallen or rolled down from the front of the glacier in irregular heaps, or to have been pushed forward by it and mixed with the *débris* from its surface, or to have been ground down underneath it by its huge masses The stratified drift is found in all parts of the State. The glacial Drift is confined to the northern and north-eastern parts, and the southern limit is marked by a line of accumulated heaps or mounds, and hills and ridges, which is known as the terminal or frontal moraine. The line of the moraine was indicated in the annual report of the Geological Survey for 1877. The full description of the great continental moraine across New Jersey is here presented.” (Report of 1880, pp. 15, 16.)

Then follow descriptions of:

- (1.) The terminal moraine, its boundaries, elevations, characteristics, &c., (pages 16 to 36);
- (2.) Moraines of recession (pages 37 to 39.)
- (3.) Local notes on the drift at Jersey City (page 39),

Palisade mountain and the Great Sandstone Valley (40 to 44), Watchung mountain (44), Passaic valley (45), Highland ridges (45 to 47), Musconetcong belt of highlands (47 to 49), Pochuck mountain and Pimple hills (49 to 52), Stag, Panther, Cranberry and Alamuche ponds (53), Jenny Jump mountain (53), Kittatinny Valley (53, 54), Kittatinny mountain (55), Delaware river valley (55, 56.)

(4.) Modified glacial drift terraces of the Ramapo, upper Delaware, &c., &c. (pages 56 to 75.)

(5.) Transported glacial drift terraces of the lower Delaware, &c. (pages 76 to 87.)

(6.) Pre-glacial drift (87 to 97.)

Of all this new, important and carefully described matter only the first subject will be here borrowed for the use of the citizens of Pennsylvania, gratefully acknowledging the admirable services which the geologists of New Jersey have rendered to American geology.—J. P. L.]

The terminal moraine in New Jersey.

*(From the Annual Report of 1880.)**

“The southern boundary line of the great terminal or frontal moraine across New Jersey has a general north north-west course from the mouth of the Raritan river, at Perth Amboy, to Morristown; thence a north course to Denville, where the direction changes to the west, which course is maintained to the Musconetcong valley, where it again turns, and thence bears west south-west to the Delaware river, at Belvidere.

At Perth Amboy the Raritan river flows along its southern foot. Here the low bluffs, which are cut on the south by the river and on the east by the waters of Staten Island sound, consist of unsorted glacial drift. The south bank of the river and the upland of South Amboy are all of stratified materials, or sedimentary beds, in which the red shale and sandstone and other characteristic rocks of the glacial moraine are entirely wanting. And nowhere along the line, as it is traced across New Jersey, is there so marked a dif-

*Ten pages of the report are copied verbatim.

ference in the superficial deposits (or covering) as at this place. On the one side there is the red shale earth, which has given character to the soil and the vegetation, whereas, on the other, are the light-colored sands and clays and gravels, constituting soils of different classes, and each covered by its own peculiar forest trees and vegetation. And Perth Amboy stands on the southernmost point of this great continental moraine. Both eastward and westward the moraine line bends towards the north. Here the ice reached its most southern limit, and, as it melted, left this impress upon the surface.

Beginning at Amboy, the line of the glacial drift, as represented by this terminal moraine, is easily traced northwest to Metuchen, and thence by Netherwood and Scotch Plains to the First or Springfield mountain. It follows closely the river bank to Eagleswood, then leaving the river, it crosses Crows Mill brook, near the clay pits of the Woodbridge Clay Company, runs just west of the Crossman Clay and Manufacturing Company's banks, to the Fairfield and Bonhamtown road, which it crosses one hundred yards west of the Easton and Amboy railroad. Thence it runs obliquely across the railroad, and approaches the Metuchen and Amboy road near the intersection of the latter with the straight New Brunswick and Woodbridge road. Thence to Metuchen it runs east of the main road, and not far from it. From Perth Amboy to the northern limit of the plastic clay formation, this line is plainly marked in both the surface materials and the shape of the country. The red shale constitutes the mass of the drift material. In the form of earth and small fragments it is the matrix in which occur the glaciated pebbles, cobblestones, and bowlders of shale, sandstone, trap-rock, gneiss, granite, syenite, conglomerates (of all the Green Pond mountain series,) magnesian limestones, and slates.

The predominance of the shaly material gives character to the soil and makes it look like the red shale country to the north of the clay belt. There is a sharp contrast between it and the soils of the latter, which are more sandy and of a light yellow color. The configuration of the coun-

try is also very strongly contrasted on the opposite sides of this line. The country on the south-west has more regular slopes and much uniformity in its structure—the result of drainage upon stratified deposits. The surface of the *moraine* is characterized by the absence of all regularity and uniformity. The hills are irregular in outline, and of uneven slopes. They are short, and hence that part of the moraine from Fairfield by Metuchen to Scotch Plains is often known as the Short Hills. The highest of these is Poplar Hill, near the Woodbridge and New Brunswick road. It is two hundred and forty feet high. The moraine surface is also marked by circular and irregular shaped depressions. Some of these are partly filled with water, and there lie as ponds among the hills. West and south-west of this line there are no such natural ponds or lakes. The structure of the drift of the moraine is well exposed to view and study in many of the clay banks west of Woodbridge and north-west of Perth Amboy. Its thickness, as cut in these excavations, does not exceed twenty feet, but in the higher hills it must be greater than this, amounting in Poplar Hill to one hundred feet at least. In places this drift is spread directly upon the beds of the plastic clay formation, but more generally it reposes upon the sands and gravels of the older pre-glacial drift. And these two drift formations are seen at many of the clay banks west and south-west of Woodbridge, as also in some of the cuttings on the line of the Easton and Amboy railroad, near Ford's Corners, and between that point and Perth Amboy. The local details as to the thickness of these drift formation may be found in the descriptions of clay pits, &c., Part II, Chapter 1, of the "Report on the Clay Deposits of Woodbridge, South Amboy, and other places in New Jersey," Trenton, 1878.

At Metuchen and eastward the inequalities of the moraine are seen along the tortuous line of the Pennsylvania railroad, which winds about among the hills as it crosses them between Metuchen and Menlo Park. A straight line across the moraine was not practicable on account of the exceedingly uneven surface. Hereabout, as elsewhere, it makes the beautifully diversified surface which is so capable of

ornamentation and so adapted to the purposes of the landscape artist, and upon it are the many beautiful residences and grounds of Metuchen and vicinity. From Fairfield to Metuchen, to Scotch Plains, and on to Springfield mountain, the Short Hills constitute the water shed between the tributaries of the Rahway river on the east and those of the Raritan river on the west. And the several railroad lines crossing it have their summits—between the Raritan and tide-water—in these hills. Thus the summit of the Easton and Amboy railroad (one hundred feet) is near Fairfield; that of the Pennsylvania railroad, one hundred and ten feet, is east of Metuchen. The Central railroad attains an elevation of one hundred and seventy-five feet near Fanwood. On the west of these hills Dismal brook and Cedar brook, flowing in opposite directions and uniting at New Brooklyn to form the Bound brook, run parallel to the line of the moraine from Metuchen to Scotch Plains. The actual boundary line of the moraine is very near the Mutchen and Oak Tree road. In Union county the moraine limit is quite near Cedar brook and west of Netherwood. Here the course is to the north and then north-east, meeting the Springfield mountain about one and one half miles east of Feltville, and not far from the Westfield and Feltville road. The moraine ascends the mountain obliquely, and at the Springfield Signal Station of the Coast Survey attains an elevation of five hundred and twenty-two feet—more than twice the maximum height of the Short Hills. Across this mountain the line is plainly marked by the accumulation of bowlders and bowlder earth which here covers the trap-rock of the mountain. From the crest of the First mountain this drift line has a north-north-west course across the valley, lying between the First and Second mountains, to the latter, near Summit. It sweeps around the north end of the higher part of this range and south of Summit Station. Here the elevation is not very different from that of the railroad depot, three hundred and eighty-one feet. The characteristic Short Hills and their accompanying depressions are very noticeable along the line of the D., L. & W. railroad east and north-east of Summit to Milburn and Springfield. There was a

great accumulation of material in this gap in the trap-rock ridge, and there are several ponds here, filling the hollows between the hills. The thickness of the drift about Milburn was such as to entirely conceal the underlying strata, leaving an apparent break in the continuity of the rock of the First mountain. All travelers on the D., L. & W. railroad are familiar with the aspect of this country, and the peculiar surface of the moraine here so well exhibited. And they can now understand that its origin was due to the glacier which stopped here and left these great heaps of confused earth, boulders, and gravel. Here, too, we find a water-shed, the drainage from the valley to the north coming out of the mountains at this place through the Rahway river and that to the south following the valley between the mountains passing Feltville at the gorge of Green brook, near Scotch Plains.

From Summit the line is traced in a westerly direction to the Passaic river, south-west of Stanly Hall. The New Jersey West Line railroad cuts into the drift hills west of New Providence Station. In one of these there is a vertical section forty feet deep where the materials are somewhat sorted and stratified, and there is much red sand and gravel in this cut. These southermost hills of the moraine have evidently been modified by the action of water. They may be of later age than the unsorted drift north of them, as it is exposed along the D., L. & W. railroad. On the First mountain, and on the Second mountain, and across the valley between them, and also in the valley along the Passaic, between the Second mountain and Long Hill, the moraine hills contain much trap-rock, derived from the north. This occurs in the form of large and quite angular masses, smaller boulders and fragments. The number of gneissic and other crystalline rocks from the highlands is greater, as also the boulders, while the amount of Green Pond mountain conglomerate and red shale earth is a little less than it is in the Short Hills. It is here, however, sufficient to give character to the surface, and it constitutes the earthy matrix in which the other materials are imbedded, as cobble-stones, boulders, gravel, &c. The soil on these

hills is like the red shale out-crop, excepting the boulders that are abundant in it. Along the Passaic river the drift mass does not appear to be so thick as it is about Milburn and Springfield, or as it is in the Short Hills. The cut on the D., L. & W. railroad show it twenty-seven feet at least at Stanley. West of the river the moraine appears wrapped around the northern point of the narrow Long Hill. As viewed from a standpoint on the east side of the Passaic, the drift mass is seen rising from the bottom of the valley on Green Village and New Providence road, near George Sheppard Page's residence, to an elevation of three hundred and fifty feet on the northern point of the ridge passing just above the cemetery and crossing the end of the hill a short distance south of the Bonnell's Mill road. There are a few scattered boulders up to three hundred and ninety feet or quite to the top of the ridge, but the great mantle of drift does not reach the crest. The trap-rock on this end of the ridge is very much altered and crumbling, indicating that the glaciation on this point was very slight. The moraine boundary runs south-west, slanting along the western side of Long Hill to the Green Village road. Thence its course is, in general, north-west, coinciding very nearly with the northern margin of the Great Swamp, after leaving which it follows the foot of the hill or ridge near Loan-taka brook, and near the north-eastern limit of Morristown to the Washington mountain at Morristown. The ridge from Long Hill to Morristown is a very prominent feature in the topography of that part of the State, and is noted for its commanding views and its almost continuous succession of beautiful park-like grounds. Madison is partly on it. The road thence to Morristown runs on it. This ridge also is a water-shed between the tributaries of Upper Passaic on the south and the branches of the Whippany on the north. It differs from the Short Hills and the more south-eastern part of the moraine in its level top and more uniform slopes. Generally its southward slopes are steep. Towards the north it more gradually disappears in the lower grounds of the Passaic valley. It does not, however, altogether lack the uneven surface, having near Morristown

several quite large hollows, one of which, the "Punch Bowl," is about sixty feet deep, and is a vast, dry amphitheater. The top of this ridge is quite level, particularly the south resembling a terrace level. It is three hundred and sixty-six to three hundred and eighty-two feet high, and one hundred to one hundred and twenty feet higher than the valleys south of it, and one hundred and forty feet above the general level of Chatham and Madison on the plain country on the north. The more uneven drift north of Convent rises to a height of four hundred and fifty-seven feet. The upper portion of this ridge appears to be generally stratified, and consists largely of sand, gravel and cobble stones, with earth derived from various sources. The soil on its southern side is everywhere quite sandy. The nature of the materials occurring in this ridge can be studied in the pits where gravel and stone are obtained for road-making. One of these is near the Kitchell place, on the southern slope of the ridge, and about two miles west of Madison. At this point a yellowish sand forms the mass of material; in it the gravel is mostly of quartzites and conglomerates with red sand-stone and gneissic rocks. The thickness of the drift mass in this ridge must everywhere be over one hundred feet, since nearly all the wells on it are of that depth. At the Drew Theological Seminary a well was dug one hundred and fourteen feet by the late William Gibbons, and then a boring two hundred feet deeper, it is said, did not get through the loose materials.

In Morristown the line of the glacial drift runs near the southern limit of the corporation, on a north-west course to the Basking Ridge road, and across Market street to the gneiss ridge. Here it turns northerly and runs north-east of the court-house; thence across the western part of the town by the residence of A. W. Cutler, and to the west end of Speedwell lake. The larger part of the town is on this drift formation. The higher part about the court-house and the Fort Nonsense ridge are gneissic surface, free from drift. The elevation of the moraine corresponding approximately to that of the Morris Green, is three hundred and seventy feet, which is not very different from

that near Madison (three hundred and sixty-eight feet), or the summit of the south part of town (three hundred and eighty-two feet.) And this is, on an average, one hundred feet above the valley of the Whippany on the north-east (two hundred and eighty-three feet and two hundred and sixty feet.)

From Morristown to Morris Plains the drift limit coincides with the division line between the gneissic rocks of the Highlands and the red sand-stone of the Triassic Age. It is difficult to trace the out-crops of the latter rock, as it is so deeply covered by the drift. North and west of Speedwell lake there is an interval extending to the Headley place—about one mile—where no true unmodified moraine material is seen. It may be covered by the stratified sands and gravels which form the bottom of the valley of the Whippany. At the Headley place, and thence north-east and northward to Morris Plains it is recognized in a series of gravelly hills and deposits which border the foot of the mountain. More accurately the line may be said to run west of the Burnham and Johnson ponds, east of the Asylum, near Pierson's saw-mill, and so along the foot of the Watnong mountains to the D., L. & W. railroad, about a half a mile north of the Plains depot. The level of Morris Plains has been made by the modification of moraine material and the excavations along the railroad, about one half mile south of Morris Plains Station, and west of it, at Johnson's mills, show it to be an immense bed of sand, gravel, and bowlders. The larger percentage of these are of gneissic rocks. Next to these in number are the rocks of the Green Pond mountain series, and then the Triassic sandstones. The height of the plains is four hundred and five feet at the Plains depot. Horse Hill, one mile south-east of the Plains Station, is higher (four hundred and eighty-eight feet.)

From Morris Plains to Denville the boundary line of the drift runs northward along the railroad west of the same and George W. Howell's residence, and west of Mount Tabor. For a half mile southward from the charcoal mill there is an interval where the drift is wanting in the valley.

Mount Tabor is a moraine hill. Denville is also drift, and its elevation above tide level is five hundred and twenty-two feet. Towards the east the drift has a very uneven surface, and Ketchum's pond occupies a hollow in it. The Boonton Branch railroad cuts across one of these depressions, and here the moraine height is five hundred and forty-six feet. Along the valley of the Den brook, south of the D., L. & W. railroad, and in the Rockaway valley north-east of Denville, the moraine has been so modified by subsequent changes that it does not appear continuous across this more recent stratified valley formation. In the latter there are no large boulders. Travelers along this road from Denville to Powerville can see this latter formation, which has probably come from a remodelling of the older moraine drift left here by the glacier. A remnant of the moraine lies on the western foot of the hill east of the Den brook and south of the depot, between the old railroad line and the new double track route. West of this, in the valley, there are low knolls of sand and fine gravel. As the glacial drift is seen on the west of this valley, on the north end of Snake Hill, it is probable that it was originally continuous across the valley. There is, at Shongum, three and one half miles up this valley of Den brook, a deposit of glacial drift, which does not appear to be connected with these accumulations lower down and near Denville. The Shongum drift in the valley, and north of the pond, is crossed by the Millbrook road. It appears to have filled the valley excepting the narrow gorge for the outlet brook. According to barometric observations this local moraine or drift body is seven hundred and forty feet above tide level, or two hundred feet higher than the similar deposits about Denville. As there is a little drift at Ninkey and Franklin it is possible that there was an extension of the glacier in this valley reaching to this point.

On Snake Hill the moraine appears wrapped around the north end, and attaining, on the point of the ridge, an elevation of six hundred and seventy feet. The upper limit of all boulders is about one hundred feet, or seven hundred and seventy feet; the crest of the ridge has a maximum

height of nine hundred and ten feet. The limits of the moraine are very plainly marked on this ridge, and here both the southward extension and thickness of the ice are recorded. In the valley on the west of Snake Hill the moraine is not traceable entirely across to the next ridge. But it is seen on the eastern and northern end of the latter, and is wrapped around it somewhat as it is on Snake Hill. It can be traced on it south-east of the D., L. & W. railroad, and its southern boundary line crosses the Rockaway and Union School road at a point half way between the two lines of the Delaware, Lackawanna and Western railroad. It is here about six hundred and seventy feet high, and it is recognized by the number of erratics and the inequalities of the surface. Thence the line runs south-south-west, and the double track line of the Delaware, Lackawanna and Western Railroad Company cuts into it, exposing to view large boulders of gneissic and other crystalline rocks and many Green Pond mountain conglomerates. The drift mass here is ten to fifteen feet thick, and reposes upon gneiss. From this point the line is traced with difficulty in a general south-westerly course, crossing the Dover and Morristown road west of the Union school-house, and returning west of Rock Eatam, a rocky knob on which there are no glacier marks or drift deposits.

Here the line comes to the south-west extension of the valley of the Rockaway, Horse Pond brook and Mill brook, whose elevation is about five hundred and sixty feet. Here, as in Den brook valley, the moraine appears to have been partly obliterated. There is, however, a part of it left on the western side of the Mill brook, near the Dover and Shongum road, stretching from the brook westward to within two hundred yards of the cross-roads, about a third of a mile long from east to west. It is a bow-shaped deposit, and curves northward at each end. The surface is very sandy. The road cut shows boulders of gneiss, conglomerates, and cobble-stones and gravel, with angular rock fragments from near localities. This section of the moraine seems disconnected east and west, but it marks the southern limit of the ice in this valley.

Going westward, the next moraine hill is east of Mines brook and west of the Pleasant Valley and Rockaway road. The hill is six hundred and forty-five feet high, has steep and smooth slopes on north, west and south, and the material, as seen in a gravel pit on the north side, is sand, gravel and cobble-stones. These are mostly of gneissic rocks, with many of quartzites and conglomerates. Eastward the slope is more gentle to the above-mentioned road. As there is no drift on the north face of the hill, east of Dover, and south of the railroad and Rockaway, between the hill and the town, the moraine line is represented as running north-west to that stream, and following it to the town. The valley north of the stream is drift, and evidently of glacial origin.

The greater part of the town stands on the same superficial formation, and its southern limit is south of the railroad depot, and passes around a small pond and the old cemetery, and then, curving northwards, approaches the main street, and follows that and the main road over the northern glaciated foot of Clinton Hill. On the north side of the town there are many very good sections showing the materials of this formation. One of these is at the side of the Mount Pleasant turnpike, north of the rolling-mills and pond. This section shows finely the confused, unsorted nature of the drift. Here are seen boulders of all sizes of gneiss, granite, syenite, sandstone conglomerates of the Green Pond mountain series, with a very few of blue limestone, white limestone and of slate; also, but more rarely, magnetite. With these boulders there are cobblestones and pebbles of all sizes. The same moraine mass is cut in a shallow pit near the cemetery and at the side of the Mount Hope road. At this point there appears to be a finer pebbly drift under the coarser boulder mass. And the former may be stratified. The surface of the moraine east of the cemetery is exceedingly uneven and full of sink-holes and some pond-holes. It is about seventy feet higher than the flat along the Rockaway, or six hundred and forty feet high. This inequality of surface is well exhibited along the road to Mount Hope, and the highest of the hills

along that road, but near to Mount Hope is more than three hundred feet higher, or nine hundred and sixty feet.

Going westward from Dover the line of drift is somewhat tortuous, following quite closely the contours of the valleys south of the Rockaway and around on the foot of the hills. The gneissic ledges at the quarry on the northern point of Clinton Hill show the glacial marks. Southward and higher on this hill there are no traces of glacial action or drift deposits. Thence westward the line curves around southward and crosses the valley of the Jackson brook, meeting the Mine Hill road near the brook, about one eighth of a mile west of Roman Catholic church. In this little valley or cove, shut in by the hills on the south-east, south, and west, the moraine mass appears to have been modified so as to form a very beautiful terrace. It is crossed by Union Hill road and the residence of Alfred Beemer; the St. Mary's school and the Roman Catholic church are on it. According to the barometric observations it is fifty feet above Dover or six hundred and forty-five feet high, corresponding to the general moraine surface near the surface just north of Dover. The same terraced drift appears north-west of the Roman Catholic church at John Hance's, and around the hill to Port Oram, where its elevation as determined by the canal level is six hundred and sixty-eight feet.

A remnant of the moraine is seen in the drift covering the northern face of the Randolph Hill ridge below the Jackson Hill mine. Here the upper limit of the drift rises to a height of six hundred and ninety feet. The many openings and the bare ledges above this level on the hill show the absence of all glacial agencies. The moraine is traversed by the road from this mine to Port Oram, and its boundary runs west of said road quite to the village, where it turns to the west and runs south of the road near the Hurd mine, and to the foot of the King Mine ridge, near the line of the High Bridge railroad. Here the line meets the long and deep Berkshire-Succasunna valley, and sweeping around the base of the King Mine hill, it makes a detour to the south, bounding the tongue of drift which was

shoved southward in this valley. The moraine lying across the great depression forms a water-shed between the Rock-away and the Black river, which constitutes the limits of the Berkshire valley southward and the Succasunna plains northward. Probably nowhere in the State can this terminal moraine be better studied in all its relations than across this valley. To the northward is the level southern part of the Berkshire valley; on each side are rocky hills, around the north end of which the moraine has been wrapped; between them is seen the wonderfully uneven surface with its hillocks, and short ridges, and sink-holes, and little ponds; southward these appear less marked until they are lost in the plain surface of the Succasunna plains. In detail the boundary line of the moraine may be described as following the western base of the King Mine ridge to a point a short distance south-west of the Scrub Oak mine, where it changes its course and thence runs in a north-west course, coinciding closely with the line of clearings to the canal and the foot of the McCainsville sandstone ridge. The canal crossing the moraine has an elevation of seven hundred and twenty-eight feet and the drift knolls may rise thirty feet above that level.

The cuttings on the lines of the High Bridge Railroad and the Scrub Oak Mine Railway expose fine sections of the drift. Near Lock No. 3, E, it is seen covering strata of hornblendic gneiss. Near Plane No. 4, E, and southward the drift mass is made up of an unusually large proportion of boulders, cobblestones, and pebbles, the drift earth being relatively very slight. The crystalline rocks as gneiss, granite and syenite constitute nearly three fourths of the whole mass of boulders, the remaining fourth are quartzose rocks from the Green Pond mountain and Potsdam sandstones, with a very few hard grit rocks and an occasional small boulder of brown hematite. Farther south there is a partial stratification observable in the arrangement of the smaller boulders, cobblestones and gravel. In places this sorted structure appears under the unsorted, confused drift mass. Going still southward the uneven surface disappears and the gravelly, sandy level of the planes is reached

Resuming the tracing of the line of the moraine, west of the canal it is found pursuing a north-east course along the eastern side of the sandstone ridge, to the north end of the same, where it turns to the west over the foot of this ridge. Thence it bends to the south-west and runs on the lower western slope of the ridge about half a mile, beyond which points its course is west and north-west across the valley to the Drakesville depot. The sandstone ridge north of McCainsville is, as it were, an inland in the plains-valley and the moraine on the west of it corresponds in its surface features as well as in the nature of its materials with the eastern segment, above described. The level here, on the south of the drift knolls, is more stony than the plains north-east of McCainsville, being paved with small boulders and cobblestones. They diminish in number and size as we get southward, and the thick stone walls about some of the fields testify to their number on the surface. Duck Pond, east of Drakesville station, lies in one of the hollows in the moraine. According to barometric observations the highest of the drift hills east of Drakesville is eight hundred and seventy feet above tide-level. Along the Delaware, Lackawana, and Western Railroad between White Rock cut and Drakesville there are several fine sections of the moraine. At one of these, fifty feet deep, and one half mile from the latter place, there is some stratification of the materials near the top of the hill. And there is here a noticeable quantity of the Green Pond mountain rocks, so characteristic and common in the moraine to the eastward, showing that the drift materials had generally come from the north and north-east and had not been derived from points much east of north. The Green Pond mountain conglomerate is so plainly marked that this evidence seems to be decisive as to the general direction of the glacial mass. Here also the blue and magnesia limestones begin to be more abundant, amounting to one percentum of the boulder mass. There are also a few sandstones (Potsdam), Oriskany sandstones, white, crystalline limestones, Trenton limestones and slate rocks, all, apparently, of a north and north-west origin.

At Drakesville there is a gap in the continuity of the moraine. On the sandstone hill south of the station there are no erratics, nor any glacial markings; nor are there any on the gneiss hill immediately to the south-west of it. The railroad cuts and other exposures do not show any such marks. It is possible that the drift has been removed from this gap or depression, through which the railroad finds its way westward. The mountain side on the north has much smooth rock surface, but these have been so worn by water as to obliterate the ice-marks, if ever thereon. Three quarters of a mile west of Drakesville there is a long and curving cut, where the drift, unsorted, is finely exhibited. The surface also is that characteristic of a moraine. About ninety-nine per cent. of the stones in the drift earth here are of crystalline rocks. None of the Green Pond mountain rocks were seen and a few only of blue limestones and slaty grit rocks. Southward the moraine extends to within fifty yards of the District Number Four school-house and the Drakesville and Stanhope road. But it was not recognized east of the Mountain Pond brook. The moraine boundary from this point is very easily traced across the Shippen Port road about one hundred and fifty yards north of the corner of Stanhope road; thence, westerly by ex-Sheriff King's residence, along the brook and pond, to the Stanhope road about one eighth mile north of the Mount Olive road corner. Proceeding west from the Stanhope road, the line runs a few degrees south of west, intersecting the next north-east and south-west road near G. S. Slaughter's home, and then, the Flanders and Stanhope road near A. Wolf's; thence parallel to and a short distance south of the road leading to Budd's Lake, until this road turns southward, and crosses it, and then assuming a westerly course approaches the lake on its north-east shore near the corner of the road to Stanhope. Throughout this distance the moraine consists of heavy bodies of unsorted boulders, cobblestones, gravel and earth, and these lie in irregular-shaped hillocks and ridges. And here, as to the westward, across the whole top of the Schooley's mountain range, it is the water-shed between the streams flowing

northward into the Musconetcong and those flowing to the south and constituting the head-waters of the Raritan. And Budd's Lake appears to have been formed by the moraine-dam, which is across the old brook, raised the water behind it until it found an outlet in the opposite direction, southward into the south branch of the Raritan river. The original outlet was towards the north-east, and probably, through Wells' brook into the Musconetcong. The slight ridge near the road crossing the outlet brook may have been the old water-shed. As the lake is said to be one hundred feet deep, and the drift hills on the north are at least twenty-five feet higher than the lake surface, we have a measure of the glacial dam which diverted the waters of this part of the valley. On the Stanhope and Drakesville road the moraine is crossed at an elevation of one thousand feet. The highest hills near it, also in the moraine, are one thousand one hundred and ten feet high (barometer observations). North of the lake and near the road to Waterloo the higher moraine summits range from one thousand and twenty feet to one thousand two hundred and fifty feet. These points are from one to one and one half miles distant from the lake.

The southern boundary of the moraine was a west-north-west course from the lake, crossing the Waterloo road a few rods south of J. Thompson's, and then the next north and south road near the top of the mountain. From this point it bends toward the south, and not far beyond descends gradually on a long oblique course into the Musconetcong valley, coming to the creek near the distillery, one mile north of Hackettstown.

The moraine across Schooley's mountain is characterized by its great elevation, its thickness, its exceedingly irregular surface and the unsorted, confused nature of the materials. The road from Waterloo, southward, quite to the lake, affords good examples of the peculiar surface inequalities. The ridges are in places scarcely more than wide enough for a good broad road, while on each side are deep hollows, beyond which are ridges and so on without any apparent order of arrangement. The inequalities are here

on a grander scale than they are in the valley eastward, or than they are further west. The bowlders in this part of the moraine are large, and among them there are many of the blue limestone as well as of other rocks which are in place in the country to the north and west. The largest of these is on the Osborne farm, one mile north-east of Budd's Lake, at the side of the Stanhope road. It has been supposed by many to be a ledge, and has been worked for years past as a limestone quarry. As exposed, it measures thirty-six feet by thirty feet, and the quarrying has gone twenty feet in depth. Its vertical diameter is unknown. Around it there are many gneissic bowlders and other drift materials.

A reference to the map will show at a glance the southward trend of the moraine as it descended from the tablelands of Schooley's mountain into the deep Musconetcong valley. And in this valley, as in those eastward, which have been referred to in this description, the moraine extends further south on its eastern side, so that the southern boundary line across the valley has a north-north-west course. That is, it does not run at a right angle across the trend of the valley. From the creek, near the distillery, it has been traced to the Waterloo road, seven eighths of a mile from Hackettstown, and thence at the foot of the ridge along the Morris Canal to the Allamuche road north of the Wagner place. In this Musconetcong valley the moraine drift is in sharp contrast with the smooth cultivated country south of it, and it makes a soil quite different from the clean limestone soil. Full of bowlders and cobblestones and diversified by hillocks and hollows, it is neither so easily tilled nor so productive as the limestone ground.

The canal is in the moraine as far as the Warrenville road. There the moraine runs westerly and its boundary line is traced west-south-west across the Petersburg road by A. R. Day's residence; thence, on the same general course to the Hackettstown and Vienna road, north of the tannery; thence, in a south-west direction in a hollow to the Danville and Beattiestown road, near John I. Schenck's farm-house; and one and one half miles south-east of the Pequest creek.

Thus far from the Musconetcong valley the moraine is a continuous range of hills and irregular drift heaps. And it has so covered the rock strata of the hills as to obscure their geology, and has produced a surface whose irregular slopes and inequalities are in sharp contrast with the regular lines, uniform slopes and the gneissic soils of the hills and mountains south of it. The line of demarcation is as well defined here as it is on the limestone in the Musconetcong valley. All who have been at Hackettstown and have gone westward over the hills to Vienna, will recognize these distinctions and be able to locate our line.

The heights of the moraine in this part of its course, as determined by the barometer, are as follows: In the Musconetcong valley, near G. Smith's, six hundred and fifty feet; on the ridge north-west of A. R. Day's, Petersburg road, nine hundred feet; on the highest peak, three quarters of a mile west of Day's, one thousand feet, and on mountain side north of Amos Hoagland's residence, six hundred feet.

In the drift on the mountain between the Musconetcong and Pequest valleys there is much blue magnesian limestone in bowlders of all sizes, and also as cobblestones and irregular-shaped masses and fragments. They are often gathered and used for making lime. Next to the limestone in quantity, but more numerous, are the hard gray sandstones and conglomerates, apparently from the Kittatinny or Blue mountain. Then comes the gneissic and other crystalline rocks. There is also much slate, generally in smaller bowlders, cobblestones, and gravel. Red (Medina) sandstones, gray grit-rocks, and chert also abound. There are many places where these moraine materials can be seen, but one of the best sections is along the stream by the side of the road to Danville from Beattyestown and not far from the grist-mill. From this side of the mountain there are fine views of the moraine to the west and south-west in the valley of the Pequest river.

Resuming the description of the moraine boundary, it is traced from the John I. Schenck place westerly around the northern end of a rocky hill south of the grist-mill and brook, and thence in a west-south-west course east of the

Townsbury road along the side of the mountain to the Mount Bethel and Oxford road, one third of a mile north of Amos Hoagland's residence. Thence the course is north-west and almost straight across the valley to the Pequest, just below Townsbury. The moraine occupies the whole bottom of the valley, excepting the gorge, sixty to eighty feet deep, which the Pequest has cut for itself through it at that place. And its surface is characterized by knolls and hollows, in contrast with the smooth valley south of it. As viewed from the south the moraine looks like a great bank across the valley. In all these particulars the valley of the Pequest here at Townsbury resembles very much that of the Musconetcong north of Hackettstown. According to barometric observations the height of the moraine east of Townsbury is five hundred and eighty feet, or eighty feet above the valley flat south of it. On the west side of the river at this place there is a shelf of drift which is higher, or one hundred and forty feet above the creek level (six hundred and sixty feet). There is here a long and good exposure of the drift on the side of the Townsbury and Butzville road, and also one of the best points for viewing the moraine in this valley, and the terraced hills south near Amos Hoagland's and the county poor farm.

One of the results of the glacier in the valley of the Pequest was the formation of a lake basin, now occupied by the Great Meadows behind the moraine. The evidence of a higher water level is found on the sides of this basin, as for example, on the hill back of Danville church, which is forty-nine feet above the meadows, and on the east, not far from Long Bridge, where there is a terrace forty feet above the meadows, or five hundred and forty feet, which is nearly as high as the moraine at Townsbury. Terrace beds occur in the plain country north of the meadows along Bear brook, Trout brook, and the Pequest river. The terrace formation can be traced north-east from the meadows to Springdale, south of Newton, and by Tranquility, Huntsville, Brighton, Andover, Strubles Pond, and almost to Pinkneysville. Near Andover the height of this level is about five hundred and eighty feet; Strubles Pond is five

hundred and seventy-three feet, and the Pequest bridge on the Sussex railroad five hundred and seventy-nine feet, all of which correspond with the top of the moraine at Townsbury, and indicate the former extension of a body of water from the terminal moraine over the Great Meadows and northward to these limits. The lowering of the Pequest channel gradually drained the lake.

Tracing the moraine boundary for a few miles beyond Townsbury is difficult, and its exact location uncertain. On the road going west from the village over the mountain (Mt. Mohepinoki) there is no moraine drift on the steep eastern face of this mountain, above the shelf one hundred and forty feet up from the Pequest, nor on the crest of the mountain, which is about five hundred feet above Townsbury. The latter consists of angular gneiss fragments and earth derived from the disintegration of rock in situation and there are no erratics to be seen. Descending towards the south-west the glacial drift is seen at an elevation (barometric) of nine hundred and fifty feet, or fifty feet below the mountain crest. Here we find an upper limit of both moraine and boulders. Of the moraine mass the prevailing stone are gneissic. There are some sandstones and conglomerates, probably from the Kittatinny or Blue mountain, some chert and many blue limestones. Fromes Hill, south-west of Townsbury, appears to be covered to its top by the glacial drift. At the eastern foot of this ridge and on the west side of Pequest creek there is a line of low drift hills which extends southward quite to the Oxford township line. These may be considered as belonging in the moraine, and as its south-western extension from Townsbury. South of these hills and east of Pequest Mine, drift, in the form of large gneissic boulders, appears on the southern slope of a limestone ridge. But the otherwise smooth and uniform slopes of the ridge do not look like a glacial drift surface. South-west of this limestone ridge are the Furnace Creek Meadows belonging to the Union Farms. These are alluvial, and probably owe their origin to insufficient drainage, resulting from the glacial drift accumulations along the Pequest near the mouth of this tributary to it.

Going south-west there is a noticeable drift hill bounded by the Furnace creek in the east and crossed by the Oxford Furnace and Butzville road. It rises to a height of over two hundred feet above the Pequest valley. On the opposite side of the creek and north of this hill there is a heavy covering of glacial drift concealing the strata underneath. There are good sections of this drift in the ravines coming down the creek. The greater number of the bowlders are sandstones and conglomerates (Blue mountain), but the larger and less rounded masses are gneissic. These latter have come but a short distance, from the Jennie Jump mountain. Blue limestones are large and abundant. In addition to these there are red sandstones, slaty rocks, chert, etc. Many of these are beautifully striated. The railroad cut, one half mile west-north-west of Butzville, presents a very good section of the drift. The upper portion of the hill, as seen in the cut, is quite sandy. Of the bowlders exceeding three feet in diameter the greater number are rocks of the Blue mountain. Among the smaller bowlders there is a greater proportion of blue limestones than among the larger sizes, but of these most are silicious rocks. The gneiss and other crystalline rocks are present as cobble-stones, and these are less numerous than the sandstones, conglomerates and other quartzose rocks. Most of the pebbles and bowlders here are finely striated. The locality is an unusually good one for the study of morainic materials. The surface of the ground on all sides is very uneven. The comparatively small amount of gneissic and other crystalline rock material at this place shows that the general movement of the carrying or propelling agent was not so much from the north-east as from the north and north-west. The moraine along the Pequest has shut in the valley of Green's Pond. This pond, swamp-like in depression, lies between the southern part of Jenny Jump range and the Frome Hill or mountain, and its natural outlet is southward to the Pequest. The incomplete drainage has made a part of the basin a very pretty lake.

The boundary of the moraine south of Butzville is near the cross-roads, three fourths of a mile from the village.

Thence it runs westward one fourth mile, and then turns and runs north-north-west along a small brook west of the Oxford Furnace and Butzville road to the narrow valley of the Pequest. Thence its course is again westerly along the foot of the Raub Hill, and south of the creek to the north-western point of this hill, near and south-east of Bridgeville. Here it leaves the Pequest depression or valley, and enters the great Kittatinny valley; and at this point it makes a bend towards the south-west, and thence runs along the gneiss ridge east of the Bridgeville and Oxford road, at length crossing it and then following it to Oxford. That part of the moraine which lies at the foot of the gneiss ridge between Bridgeville and Oxford consists of sand, earth, gravel, cobble-stones and small bowlders, principally of slate, blue limestone and Blue mountain rocks, forming hills whose outlines are smooth and whose slopes are steep and wanting the greater inequalities so common to glacial drift. The highest of these hills on the west of the road has an elevation of four hundred and ninety feet above tide level. One east of the same road is five hundred and twenty feet high. Very few bowlders on the surface are over two feet in length. The greater number of the cobble-stones and bowlders are rocks from the Blue mountain. There are very few gneiss or other crystalline rocks. The southern end of this range of hills is cut near the school-house by the road leading from Oxford eastward. At this point there is considerable sand in the mass, and some stratification is noticeable. The hills south and south-west of Oxford are bare of all glacial drifts, so that it is the southernmost limit of that formation in the western part of the State.

Towards the west the drift hills continue from near Oxford and south of the Pequest to the Belvidere line, about one third of a mile south of the H. J. Butler farm-house. The top of the hill is about five hundred feet high, which agrees with the height of the hills near the Oxford and Bridgeville road. The hill is of blue limestone, covered in places by a quite thick mantle of unsorted boulder drift. Of the loose stones herein perhaps ninety-nine per cent. are

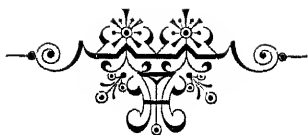
from the slate of the valley and the sandstones and conglomerates of the Blue mountain. There are some blue limestone and a few cherty stones, and occasionally Helderberg limestone and Oriskany sandstones are seen. Some of the bowlders at this locality are large, four or five feet long. From this point the line of the moraine has been represented as crossing the creek and following the foot of the bluff along North Water street to the Delaware. In consequence of the changes in the surface made by water and the partial obliteration of the moraine there is some uncertainty in the line as it is drawn through Belvidere. There are here, and extending east-ward, south and also northward, several terraces from the present river flat or flood plain up to a height of four hundred and five feet. The latter borders the Beaver brook depressions, and Sarepta and Bridgeville are on it. The plain west of Oxford, and stretching south to Roxburg is also a part of the same general level. Belvidere (south of the creek) stands on a lower terrace. These terraces indicate a period of floods and broad streams which swept away the moraine near the river and re-deposited its material on these broad flats. It is possible that the moraine, as left by the great glacier, extended a little further south down the valley of the Delaware. The drift on a low hill one mile south of the town and west of the Harmony road may be a part which has not been altogether modified. But there are no traces of it on the slate hills west and south-west in Pennsylvania. And these appear to have limited it on the south, as it is not seen on them. The extension of the line, in order to connect the Belvidere hills with the similar deposits west of the Delaware, must follow the river to the valley of the Jacobus creek, whence it has a westerly course near Bangor to the Kittatinny mountains near the Wind Gap.

We have a measure of the thickness of the ice or the upper limit of the moraine on the sides of the Manunka Chunk mountain, two miles south of Belvidere. This is a high slate hill, whose upper portion is cone shaped. Its elevation is six hundred and fifty feet. The bowlders and boulder earth are in mass to within about ninety feet of

the summit. On the higher part of the hill or mountain, the bowlders are comparatively few in number and small. Nearly all of them are either sandstones or conglomerates from the Blue mountain. In the drift on the lower slope these rocks constitute the larger portion. With them there are blue limestones, chert, and slate, but no gneiss rocks. The absence of the latter would appear to indicate that there was no movement of ice from the north-east, or from any point east of that quarter.

*Elevations above Mean Tide of Glacial Drifts on the Line
of the Terminal Moraine.*

1. Poplar Hill, Woodbridge,	240
2. Summit, Second mountain,	380
3. Long Hill,	(350)
4. Madison, (ridge south-east,)	366
5. South-east of Morrison,	382
6. Green in Morristown,	370
7. Morris Plains,	405
8. Ketchum Pond, (Boonton Branch Railroad,)	556
9. Snake Hill, (north end,)	(670)
10. South-east of Rockaway, (between two lines of Morris and Essex Railroad,)	(670)
11. Gravel Hill, south-east of Dover,	(645)
12. Dover, (moraine north of the town,)	(640)
13. Near Mount Hope,	(960)
14. Canal level, Port Oran,	668
15. Jackson Hill Mine,	(960)
16. Succasunna Plains, (north of,)	(700)
17. Hills east of Drakesville depot,	(870)
18. Hills near Drakesville and Stanhope road,	(1100)
19. Hills south-east of Waterloo, (one and one half miles north of Budd's Lake,	(1250)
20. Valley north of Hackettstown,	(650)
21. Ridge near A. R. Day's, north-west of Hackettstown,	(900)
22. Side of mountain near Amos Hoagland's,	(600)
23. Townsbury,	(580)
24. Side of mountain at Townsbury,	(660)
25. Mount Mohepinoki, west of Townsbury,	(950)
26. Hill south of Oxford Furnace,	(600)
27. Hill east of Oxford and Bridgeville road,	(520)
28. Hill west of Bridgeville,	(490)
29. Hill east of Belvidere, (H. J. Butler's place,)	(500)
30. Manunka Chunk mountain,	(560)



Notes and Corrections to Chapters I-XVII.

Page 62, paragraph 4.—The Portland kame is finely seen along the line of the Portland and Bangor R. R. which ascends the kame immediately west of Portland. The kame is seen on the north side of the railroad as a long, low ridge with undulating crest. It is continuous as far as Johnsonville, just east of which the railroad cuts through it leaving the kame to the south. (Here is Indian Fort.)

Page 61, paragraph 3.—Striæ on slate at North Bangor slate quarry elevation 590' A. T. bear S. 31° W.

Creep striæ on the north side of the same quarry bear N. 63° W. These last are much smaller than the glacial striæ.

Page 74, paragraph 5.—That is, in ascending the Pocono plateau from McMichael's P. O. to Long Lake, the outside edge of the moraine is sharply defined at a point on the road about one and one half miles north-west of the village. From this point onwards the road traverses the unglaciated flank and top of the mountain to and beyond Long pond, north of which the moraine is again encountered.

Page 75, paragraph 1.—Pocono knob is crowned by steep cliffs of sandstone belonging to the upper portion of the Catskill formation, with the loose broken angular pieces of which its steeply sloping sides are covered. Accumulations of drift a half a mile in width lie at its base. Although the knob was climbed three times in the search for the moraine the connection between the moraine hills north and south of Dry Gap was not discovered. Instead of winding around the knob, as represented in the map, it is possible that the moraine crosses it near Dry Gap, and that the knob was an island and not a peninsula at the edge of the ice-sheet.

Page 77, paragraph 3.—The photographic view in Plate IX exhibits the front of Long Ridge immediately back of the house of D. Heller, on the Pocono plateau. The frontal ridge of the moraine is about 50 feet high, being lower and more even than the more conspicuous hinder portions of the moraine. The knobby character of the back of the moraine, as photographed for example in Plate XVII, is in strong contrast with its frontal low ridge, as exhibited in the photographs taken at Bangor, Saylorsburg, and Pocono Mountain (Plates I, VI, IX.)

A good section across the moraine is made by the road leading west from Pocono station. From the station westward to the Sullivan road one travels over a sandy, nearly level plateau covered by scrub oak and an occasional pine. Soon after crossing the Sullivan road, low drift hills appear, and the road becomes stony and difficult to travel upon.

These hills are interlocked with one another and covered by fragments and boulders (often striated) of transported rock. After crossing nearly two miles of such material, the road being compelled to wind around some knolls while crossing others, and, after passing *Deer Lake*, the boulders become larger and more numerous, an indication that the front edge of the moraine is near at hand. Finally, just west of the swamp, at Heller's deserted saw-mill, the last ridge is reached, and from its summit a level, driftless plain can be seen extending out to the front escarpment of the mountain. This frontal ridge, as already mentioned, is not so high and has not such characteristic glacial topography as the drift hills further back. It is covered with transported boulders often many feet in diameter. While fragments of Pocono sandstone were by far the most abundant, and were almost always angular, though often striated, rounded stones, many other rocks, including Laurentian syenite, were collected.

Page 79, paragraph 2.—A remarkable ridge of striated drift is connected with the back (east) portion of the moraine, the valley being narrow; but further north-east the valley widens and no drift hills appear until a point one

half mile north-east of Stormville is reached, a wide plain of stratified drift taking their place.

Page 80, paragraph 5.—In Barrett township, upon the summit of the mountain, certain kame-like ridges near the house of J. H. Price are probably related to a ridge of unstratified drift of morainic character which crosses the plateau.

Page 81, second line.—That kettle-holes are due to a vortex motion of the water is, therefore, not so probable as the hypothesis that they were once occupied by buried masses of ice left when the glacier retreated, which masses of ice, melting subsequently, left holes where they lay.

Page 81, paragraph 4.—In their external features as well as by their internal characters, the shape and material of their pebbles, the lower and most recent terraces are identical with the *river gravel* or Trenton gravel of the region south of the terminal moraine. Since moreover they are purely of an aqueous origin, their consideration is deferred to Report Z'.

Page 82, paragraph 2.—These striæ at the base of Pocono mountain bearing S. 89° W. are at an altitude of 1090' A. T.

Page 82, paragraph 4.—These striæ S. 61° W. lie at 1130' A. T. Many striated surfaces were noticed between Forks and Tannersville the general direction being more west than south. Three fourths of a mile north of Tannersville, striæ on the same road bear S. 58° W. elevation 975' A. T.

Page 84, line 2.—The most elevated in the township occur upon the northern side of the Kittatinny mountain where they were noticed in the vicinity of Tatamy's Gap. Close to the summit of the Gap (elevation probably 1000' A. T.) striæ on a sloping surface of rock bear S. 31° W. Several other localities occur further down the mountain, but as all were on sloping rock surfaces they are probably deflected more or less from the true glacial direction.

Page 85, paragraph 2.—Many rock surface covered by striæ were noticed in the vicinity of the Water Gap, both near the river and on the mountain.

The whole north face of the Kittatinny mountain is covered by striæ having a S. by W. direction.

On the path leading from the Water Gap House to the summit of the mountain ("True Ridge Path") many striated surfaces may be observed.

Just beyond the side path to Child's Arbor striæ bear S. 13° W. Beyond the arbor (above Winona cliff) distinct striæ on the east side of a nearly vertical rock bear S. 16° E. These last are of course deflected by the steep face of rock across and over which the glacier has moved.

A much better exposure somewhat farther on and higher up gives S. 18° W. Still another is S. 5° W., the rock being finely embossed. These are in Clinton red shale and run up hill.

Another locality on the same formation shows striæ running also west of south. Just beyond the "one mile" post, near a rustic bridge, distinct striæ on red shale run directly up hill, pointing S. 4° W. These are all well defined.

A few steps higher some ill-defined striæ running nearly north and south may be seen; and again a little higher and the same phenomena are repeated.

Near the "Promontory" a number of embossed and striated surfaces occur at an elevation of four hundred and twenty feet above the river.

At "Prospect Rock" a large embossed surface is covered by striæ bearing about S. 15° W.

A boulder of Oriskany sandstone was here found.

Still higher, on top of the ridge of red shale, are many *roches moutonnées*, with striæ bearing nearly north and south.

Beyond here rises the mountain of white Medina sandstone, the mountain side being covered with loose blocks of the sandstone. Occasional small boulders of red shale are the only indications of glaciation. Yet the hard sandstone on the summit of the mountain is in several places smoothed off, as though by ice and, as will be stated when describing the boulders of Monroe county, transported and striated boulders prove the passage of the glacier across the mountain.

It is of interest to observe that these high-level striæ on the Kittatinny mountain, some miles back from the ter

minal moraine, have a more nearly north and south direction than those at lower levels. On both sides of the mountain, in Northampton and in Monroe counties, the valley striæ are influenced by the trend of the valley to veer westward.

The finest examples of striæ near the Water Gap are on *Table Rock*, 380 feet above the river. A large surface of Clinton red shale is here bared, and covered by striæ. These vary in direction from S. 7° W. to S. 25° W., the most constant direction being S. 14° W. One bearing S. 25° W. crossed, or was crossed by, another bearing S. 14° W.

In one case a single stone has made two cross scratches in different directions.

(Page 86, third line.—See photographic plate XV.)

In addition to the striæ upon the mountain, many others were observed in Smithfield township.

On the Delaware, at the mouth of Cherry Creek, striæ bearing S. 17° W. occur upon the shale, and 100 feet below is another exposure where they bear S. 20° W.

The rocks directly below the Kittatinny House are smoothed, but show no striæ. Near the station on the railroad, striæ bearing about S. 12° W. run diagonally up a steep slope. Here also striæ may be seen upon a perpendicular cliff, running up diagonally in a southerly direction. The upper end of one of these striæ ends in an irregular, jagged gouge, where the graving stone had caught and been ground in into the softer rock. The striæ on this vertical face are sometimes curved, the concave side of the curve being above. Others are variously deflected from the true course of the surmounting ice. The average northward *dip* of these striæ is 20°. Nearer the Gap and in the Gap no striæ were seen.

Opposite the Kittatinny House, on the road, the bared rocks show striæ bearing S. 17° W. running *down hill*.

On the road to Tatamy's Gap, a quarter mile west of the Water Gap House, good striæ, running up hill, bear S. 28° W.

A quarter mile further west, at a bend in the road, th

bear S. 25° W. Just beyond, on top of the hill, they bear S. 15° W. These are all in Clinton red shale. It will be noticed that on ascending the hill the striæ develop a more southward direction.

On the road below the Water Gap house faint striæ bear S. 10° W. The rock is here hard and the striæ are consequently much more faint than those in the soft red shale.

Page 87, paragraph 1.—The direction here stated, S. 17° W., is an average.

Page 88, paragraph 5.—Higher up on the mountain are other large limestone boulders, boulders of Oriskany sandstone, &c.

Page 89, paragraph 2.—It is of interest to observe that boulders are scarce and till almost absent throughout a large part of Pocono township, and this is especially true for a zone lying approximately five miles back from the terminal moraine. So rare is the drift on the more elevated land of this region that the writer was for a time doubtful whether it had been glaciated or not; but the discovery of striæ, and afterwards of the terminal moraine, were decisive as to glaciation. Certain large accumulations of till and boulders in this region are to be classed as moraines of recession or mountain moraines.

A class of boulders of some importance are those which, at certain localities, appear just *outside* of the terminal moraine, like *outliers*. Thus, at Saylorsburg, on the side of a hill 500 feet in front (S. W.) of the moraine ridge, there is a large collection of Oriskany boulders. These have been carried only this short distance from their outcrop in the opposite ridge, yet they were probably carried by ice.

Sometimes the *fringe* of outlying boulders is wider. Thus, west of Effort, on hills nearly three miles west of the moraine, certain rounded glazed sandstone boulders were observed. No till accompanies these rounded, ancient-looking boulders. In other places in Chestnut Hill township, as north-east of Effort and east of Merwinsburg, smoothed boulders, sometimes three feet long, were observed. They may be the result of glacial floods, or, on the

other hand, they may represent the glacial *fringe*, as described in the chapter on Beaver county.

Page 89, paragraph 4.—This remarkable ridge of bowlders is, perhaps, a portion of a true *moraine of recession*, being approximately parallel to the terminal moraine, while ten miles back from it.

Between Canadensis and Oakland till abounds and bowlders are numerous and often of large size. If a mountain moraine, it is probably local.

Page 89.—The drift accumulations along the base of the mountain in Paradise township between Oakland and Forks, cut through by the railroad, are probably of similar nature.

It should be observed that these *mountain moraines* and *moraines of recession* are often more conspicuous than the terminal moraine properly so called.

Page 101, paragraph 3.—At least no such pebbles were noticed in prosecuting the survey here.

Page 110, paragraph 6.—Generally in the center of the valley.

Page 113, paragraph 4.—The course of the moraine through Briar Creek and Centre townships is not free from doubt. It is possible that the true moraine climbs Lee's mountain near the border of Columbia and Luzerne counties, and that the bowlder accumulations about to be described lie west of the moraine and are to be classed with the higher level stratified deposits of the Susquehanna valley.

Page 116, paragraph 1.—That is, the accumulation of bowlders regarded as the moraine.

Page 116, paragraph 6.—These striæ "bearing S. W." are indistinct.—Paragraph 8. There can be no doubt about the normal aspect of the moraine in the Red Shale valley.

Page 117, line 4.—That is, to within half a mile of the western road.—Paragraph 4. Thus it is very possible that the bowlders in the valley south of Lee's mountain was carried through these notches by floods and tumbled upon the plain below to a distance of a mile or more from the base of the mountain.—Paragraphs 5 and 6. [I have inserted these data in Mr. Lewis' report to make the situation plainer.—J. P. L.]

Page 118, line 3.—But as there is some doubt about the moraine west of the road, south of the mountain, it is only safe to say that the moraine ascends the south slope of Lee's mountain somewhere within a few miles of the road.

Page 118, bottom line.—Glacial striæ bearing at right angles to the moraine occur one quarter of a mile north of Jonestown.

Page 119, paragraph 4.—These striæ occur within a mile of the southern edge of the moraine.

Page 122, paragraph 2.—Specimens of striated Hamilton slate were collected near the bridge at Cole's Mills (Water-ville), at the front of the moraine, here somewhat modified by water action.

On the road going north from here on the west side of the creek, the moraine forms a series of low ridges lapping up on the hillside from the valley. The precise edge of the moraine on the hillside can be fixed within a few yards. Nowhere is its edge more precise. Hardly a single rounded pebble or boulder was found on the hill against which the moraine here rested.

The moraine laps along the side of the hill forming the west side of Fishing creek (see Fig. 8), gradually ascending it, and finally resting upon the summit in the lower part of Sugar Loaf township.

Photographic plate XVII was taken from near the house of W. E. Cole, looking south-east. It shows the *back* of the moraine, the *front* edge of which is nearly two miles further down the creek. Much of the material is stratified. The Episcopal Church of St. Gabriel, somewhat below, stands upon a portion of the moraine.

Photographic plate XVIII exhibits a field on the summit of the hill bordering Fishing creek crossed by the moraine. The moraine winding up the side of this hill can be seen from the opposite side of the creek, a half mile distant, being distinguished by the abundant boulders in the fields.

Glacial striæ were seen upon the road leading up Cole's creek, one half mile north of its junction with Fishing creek.

Page 135, paragraph 3.—Boulders are most abundant and

the mantle of *till* is thickest, also, on the north side of a mountain.

Page 135, paragraph 3.—This ridge is more regular than a kame.

Page 143, paragraph 3.—Specimen No. 9313.

Page 158, paragraph 3.—See figure on page plate 18.—Line eight from bottom.—No *un*modified drift occurs south or east of Steamburg.

Page 181, paragraph 4.—In this county, as throughout western Pennsylvania, the moraine is frequently several miles in breadth.



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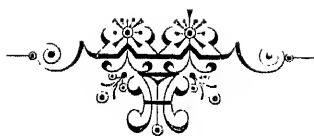
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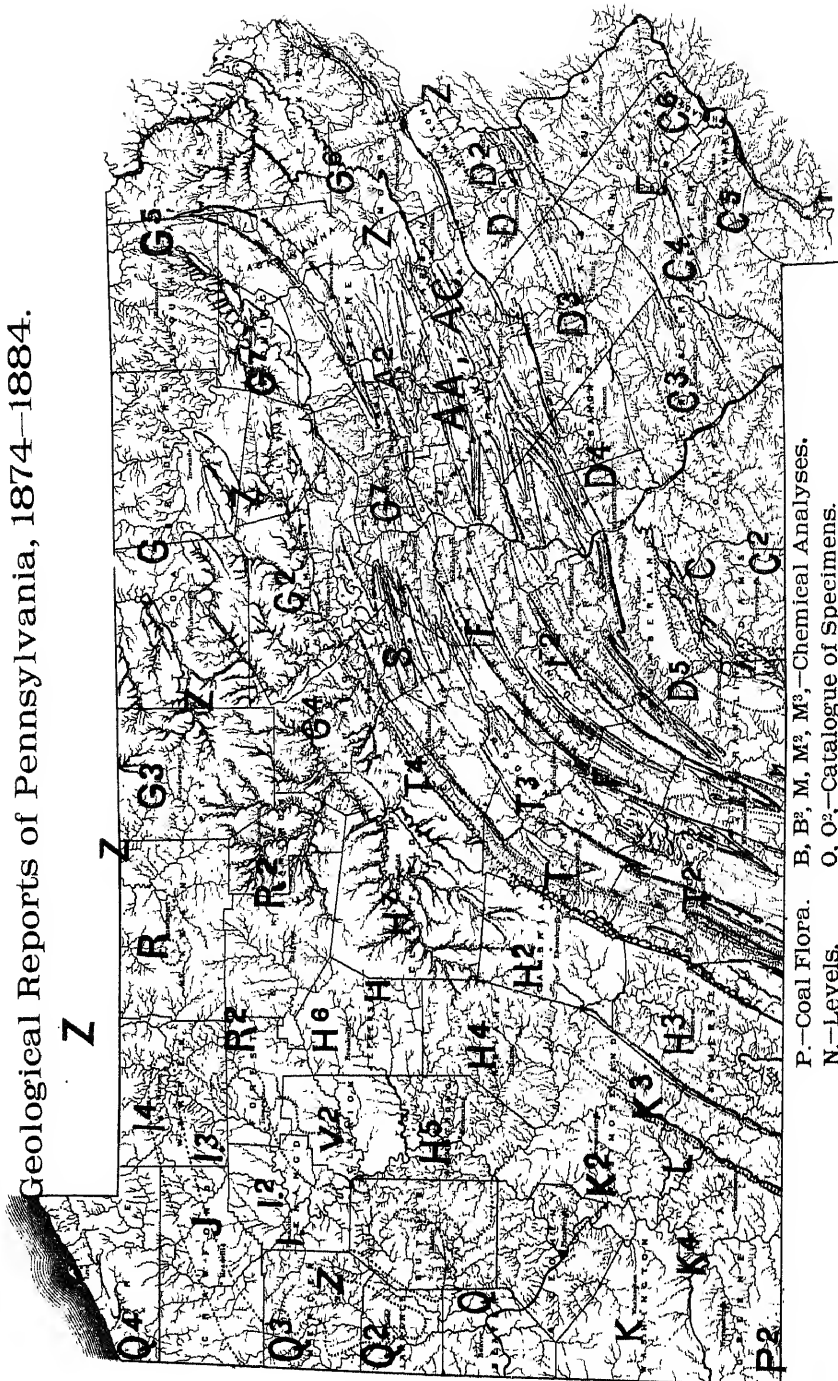
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THE PUBLICATIONS

OF THE

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April 1, 1884.